



SEA OF SOUND

Educator's Guide

Dear Educators,

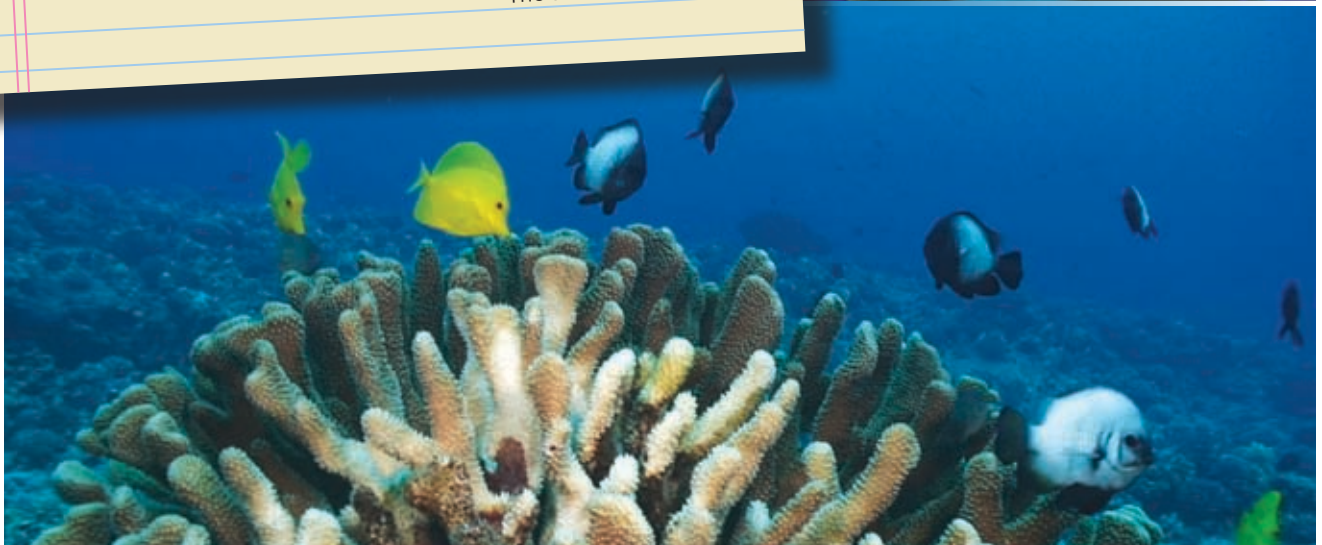
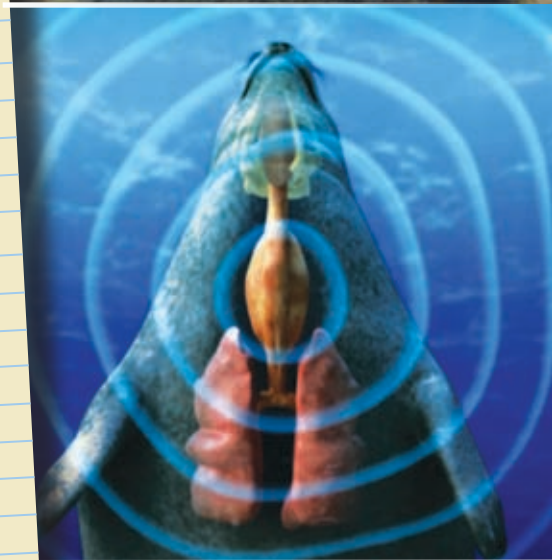
Dive with us beneath the waves to explore an emerging realm: the rich diversity of underwater sounds. *Sea of Sound* shows how animals make and use sound, discusses the sources of human sounds in the ocean, and explores the interface where these two meet. The feature video combines spectacular live action with computer animations and a lush soundscape. The result is an engaging experience created specifically for education.

Then dive deeper. There are eight classroom-ready activities to choose from including data exercises, webquests, debates, and hands-on lessons. There are even animal sounds and analysis software for lab work.

Appropriate for grades 7-12, these materials cross disciplines, presenting biological concepts about behavior, evolution, anatomy, and physiology, as well as critical physics concepts about energy and sound waves. This is real-world science and technology in a unique, authentic context.

We hope that both you and your students will enjoy learning about the sea of sound!

—The *Sea of Sound* team



BIODIVERSITY OF MARINE SOUND

Educator's Guide

What's in this Educator's Guide	3
Watching the Video	7
Sonar Debate	20
Congressional Hearing	24
Listen for Whales	29
Sound Masking	59
Biodiversity of Marine Sound	73
Extreme Animal Communication.....	105
Seeing Sound	119
Speed of Sound	140

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The **Cornell** Lab  of Ornithology



Cornell University

WHAT'S IN THIS EDUCATOR'S GUIDE

Tools for watching the video

Included are:

- An **expanded table of contents** for the *Sea of Sound* video so you can choose the most relevant sections for your class.
- A *Sea of Sound* **viewing guide** (both teacher and student versions) with straightforward questions for your students to answer as they watch the feature video.
- A set of **discussion questions** will help you review and explore the most important content from the film.
- A **table of contents** for the Interview with Dr. Christopher Clark from the Cornell Lab of Ornithology's Bioacoustics Research Program.
- **Standards alignment** information for both the National Science Educators Standards as well as the Ocean Literacy Principles.

Classroom-ready activities

There are eight activities to choose from.

Classroom Lessons (see Educator Resources on DVD)

➤ **Sonar Debate (1–3 class periods)**

- Do the benefits of using sonar outweigh the costs? Explore sources supporting and opposing the use of sonar in oceans, then hold a classroom debate.

➤ **Congressional Hearing (1-3 class periods)**

- The Right Whale Listening Network—who should fund it? Hold an informational hearing for U.S. Senate Committee on Environment and Public Works. Students represent diverse viewpoints more complex than simply pro or con.

➤ **Listen for Whales (1–3 class periods)**

- Learn about the endangered North Atlantic right whale with a webquest focused on the Right Whale Listening Network, which uses underwater sounds to protect the whales.
- Use authentic annual data from the Network to deduce important life history traits that are key to the right whale's behavior. Compare annual data to real-time data.

➤ **Sound Masking (1–2 class periods)**

- Experience sound-masking as students read aloud to one another over increasing ambient noise.
- Explore sound-masking with a webquest that examines sources and biological effects of sound-masking. Online audio clips show whale calls with and without ambient noise.
- Work with authentic sound data from Massachusetts Bay that documents sound-masking, where sounds such as boat engines interfere with animals' abilities to communicate with one another.

➤ **Biodiversity of Marine Sound (one class period; optional use of sound analysis software)**

- Compare and contrast sound use and production for five groups of animals: crustaceans, fish, seals, baleen whales, and toothed whales.
- Explore, measure, and imitate animal sound recordings using Raven Lite software*.



WHAT'S IN THIS EDUCATOR'S GUIDE

- Utilize marine animal recordings to explore the relationship between body size, frequency of sound, and how each animal group uses sound.
- **Extreme Animal Communication**
 - Explore wavelength with the low moans blue whales use for long-distance communication and the high-pitched clicks bats use for echolocation. Manipulate the sounds using Raven Lite* by speeding them up or slowing them down, so they're audible to human ears.
- **Seeing Sound (one class period; optional use of sound analysis software)**
 - Record and visualize sounds using the Raven Lite program.* Use sound data to explore concepts of frequency, amplitude, and periodicity. Predict the visual form of bird calls and test predictions with Raven Lite.
- **Speed of Sound (one class period)**
 - Use real, recorded sound data* from African elephants and humpback whales to calculate the speed of sound in air and water.

* A special *Sea of Sound* version of Raven Lite sound analysis software is included on the DVD and available through seaofsound.org. This software installs with a complete set of sounds. For the four lessons that explicitly utilize the software, you will find the sounds in the “File” menu under “Open Sound File.” You may also find it useful to use sounds with the other lessons. A variety of animal sounds are accessible from a “Sea of Sound Playlist,” also found in the “File” menu.

National Science Education Standards

UNIFYING CONCEPTS AND PROCESSES: Change, Constancy, and Measurement; Evolution and Equilibrium; Form and Function

PHYSICAL SCIENCE: Interactions of Energy and Matter

LIFE SCIENCE: Biological Evolution; Interdependence of Organisms; Matter, Energy and Organization in Living Systems; Behavior of Organisms

SCIENCE AND TECHNOLOGY: Understanding About Science & Technology

PERSONAL AND SOCIAL PERSPECTIVES: Natural Resources; Environmental Quality; Science and Technology in Local, National & Global Challenges

Ocean Literacy Principles

For more information on the ocean literacy principles, see the framework diagram at oceanliteracy.wp2.coexploration.org.

The ocean supports a great diversity of life and ecosystems (5).

Grades 6–8

- The diversity of ocean ecosystems allows for many unique life forms with many unique adaptations (B).
 - Organisms in the ocean exhibit an amazing variety of adaptations to sound, density, pressure, patchy food distribution and other environmental factors (B5).



WHAT'S IN THIS EDUCATOR'S GUIDE

- Many marine animals from shrimp to whales rely on sound to communicate, find prey and mates, and sense their environments. Sound travels through the ocean much better than light does (B9).

Grades 9–12

- Organisms in the ocean exhibit a wide variety of adaptations to survive in a watery environment (C22).
- Since sound travels through the ocean further ~~and faster*~~ than light does, many marine animals, from shrimp to whales, rely on sound to communicate, find prey and mates, and sense their environments (C27).
- Many large whales use low-frequency sound to communicate across entire ocean basins. Many toothed whales use echolocation to find and/or capture prey. Pistol shrimps use blasts of sound to shock prey (C28).

The ocean and humans are inextricably interconnected (6).

Grades 6–8

- Human activity contributes to changes in the ocean and atmosphere (D).
 - Pollution affects life in the ocean (D18). (*Sea of Sound* note: This includes noise pollution.)
- Individual and collective actions are necessary for maintaining, conserving and sustaining a healthy ocean (E).
 - Scientists are still learning about marine organisms and ocean ecosystems. New information is useful for helping guide policy decisions and individual actions (E1).
 - It is important for the public to learn about the issues regarding the oceans and to take action (E6).

Grades 9–12

- The exponential growth of human populations, together with technological advances, have exacerbated changes in the ocean and atmosphere (D).
 - Humans contribute to biological changes of the ocean ecosystems (D11).
 - Ocean ecosystems are altered by activities that change predator/prey relationships (D12).
- Achieving sustainability of the diverse species in the ocean depends upon collective and individual action based on scientific research and exploration (E).
 - It is important for the public to learn about the issues regarding the ocean and to take action (E6).

Standards-alignment matrices are available on the DVD or at seaofsound.org.

* At the time of this publication, the Ocean Literacy site incorrectly states that, in water, sound also travels faster than light. This is not true. Sound travels faster in water than it does in air, but light travels far faster than sound in air or water.

Acknowledgments

By Elizabeth Rice, Ph.D and Susan Dodge M.S.Ed, Creative Curriculum, for *Sea of Sound*. Edited by Marc Dantzker. Designed by Joanne Avila. If reproducing the lesson, please cite *Sea of Sound* as the source and provide the following URL: seaofsound.org.

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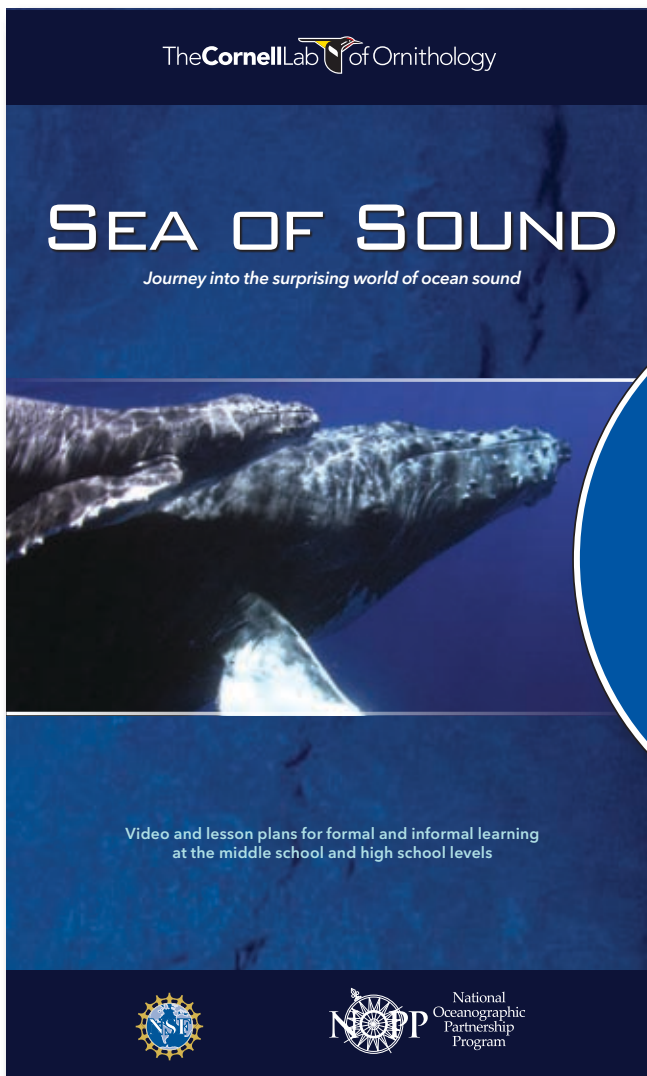
WHAT'S IN THIS EDUCATOR'S GUIDE

Tools for watching the video

Many students may not be familiar with the sounds of the ocean beyond crashing waves and the sounds of a beach or harbor. Before you watch the video, you may want to activate students' preconceptions and prior knowledge about sound in the ocean. Ask, "When you think of sound in the ocean, what do you think of? List all the sources of sound in the ocean that come to mind," or "What is the most common sound in the ocean?" Solicit student answers and create a list of ideas for all to see.

The **Viewing Guide** provided below is a set of straightforward questions intended to guide students through a critical and detailed viewing of the movie. Questions are grouped according to chapters of the movie. You may wish to stop the movie after each chapter to review and discuss the concepts presented.

After the **Viewing Guide** is a set of **Discussion Questions** intended to facilitate analysis, application, and synthesis of the concepts presented in the video.



WATCHING THE VIDEO

Viewing Guide: Teacher Version

Answer these questions as you watch *Sea of Sound*.

Introduction

1. What is the source of the most ubiquitous, or ever-present, sound in the ocean?

Bubbles (from waves and other sources) are the most ubiquitous sound in the ocean. The most ubiquitous biological sound is from snapping shrimp.

2. How do natural phenomena such as earthquakes and weather make sounds in the ocean?

Wind and waves make bubbles. Raindrops and lightning also produce sounds in the ocean. Earthquakes produce sound as well. Students may note that volcanic eruptions may also create sound.

Animal Sounds

3. During this part of the video you will learn about a variety of animal sounds in the ocean. Fill in the blocks of the chart as you learn about each animal.

Organism	Habitat	Why this organism creates underwater sound	How this organism makes and/or uses underwater sound
Snapping Shrimp	<i>Reefs in tropical and temperate waters around the world</i>	<i>To communicate, avoid predators, and kill prey</i>	<i>Cavitation; pressing the large claw together creates a jet of water that is moving so fast that it opens up a vacuum-filled hole (bubble) in the water. When the jet of water slows down, the vacuum-filled bubble collapses (implodes). The implosion makes the sound.</i>
Soldier Fish	<i>Reefs</i>	<i>Alarm and other functions not shown in the video</i>	<i>Uses sonic muscles connected to ribs, which are connected to swim bladder to produce sound; sense sound using the swim bladder, which passes the signal to the ears.</i>
Bearded Seal	<i>Under the ice around the Arctic Ocean</i>	<i>Underwater sound signals territoriality and social rank. (Possibly also mate attraction.)</i>	<i>Underwater, the seals' elastic airway radiates sound like a fish's swim bladder, but the structure that creates sound is still unclear.</i>



WATCHING THE VIDEO

Viewing Guide: Teacher Version

Organism	Habitat	Why this organism creates underwater sound	How this organism makes and/or uses underwater sound
Blue Whale	Open ocean	To communicate and find mates across thousands of kilometers. (While we know that this is a classic mating call, and we know it can be heard thousands of kilometers away, scientists can't figure out how to "prove" that mates are actually choosing males over those distances.)	(Anatomy not discussed in video); sound travels thousands of kilometers via sound channels, created by natural variations in speed of sound. This is called the SOFAR channel.
Narwhal	Arctic oceans, under ice	Uses echolocation to image the underwater environment and locate prey. (They also whistle and click to communicate, attract mates, coordinate movements, etc.)	Create intense clicks with a set of air sacs in their nasal passages. (Remember that their blow holes are their nostrils). They have an additional organ on their foreheads, the melon, which focuses sound, helping tighten it to a beam.

Anthropogenic Sounds

4. How does the Navy use underwater sound?

Active sonar, a critical military tool, is the human version of echolocation. The Navy uses several types of sonar to find submarines.

Though not shown in the video, the Navy also uses sonar to navigate in tight areas, and to scan for explosives (mines).

5. What is seismic surveying?

Geophysicists use seismic surveying—a type of sonar—to create images of the earth's crust for geological study and to look for energy resources. Controlled explosions of compressed air make low-frequency pulses directed into the sea floor. Return echoes are captured by hydrophones. The technique reveals features in the earth's crust including ancient riverbeds, old impact craters, and lift-and-thrust zones.

6. The narrator states that the most pervasive human sounds are caused by global commerce. Describe those sounds and why they are so wide-ranging.

Huge tankers and container ships create noises from engines and propellers. Propellers create cavitation bubbles, heard only underwater. When an individual ship passes, it completely fills the area with low-frequency sound for hours. There are thousands of large ships in the water all over the world, and they're almost always on.



WATCHING THE VIDEO

Viewing Guide: Teacher Version

Changing the Ocean Soundscape

7. What kinds of sounds do North Atlantic right whales create and why are those sounds so important?

North Atlantic right whales communicate using low-frequency calls. They are social animals and rely on sound traveling long distances for survival and reproduction.

8. What is masking? What is the effect of masking on the North Atlantic right whales?

Masking is obscuring or covering up whale calls with other low frequency sounds. The sounds from right whales are often masked by human sounds. Whale calls that once reached 2,000 square km today reach only 200 sq km. Whales are functionally blinded until nearby ships pass.

9. How are scientists and engineers using the North Atlantic right whales' sounds to try to protect the population?

Busy shipping lanes crisscross the North Atlantic right whales' range; ships can hit whales. An early warning system in Massachusetts Bay uses computers on auto detection buoys to record whales' primary contact call, the upcall. The system notifies ship captains to slow down when right whales are in the area.



WATCHING THE VIDEO

Viewing Guide: Student Version

Answer these questions as you watch *Sea of Sound*.

Introduction

1. What is the source of the most ubiquitous, or ever-present, sound in the ocean?
2. How do natural phenomena such as earthquakes and weather make sounds in the ocean?

Animal Sounds

3. During this part of the video you will learn about a variety of animal sounds in the ocean. Fill in the blocks of the chart as you learn about each animal.

Organism	Habitat	Why this organism creates underwater sound	How this organism makes and/or uses underwater sound
Snapping Shrimp			

WATCHING THE VIDEO

Viewing Guide: Student Version

Organism	Habitat	Why this organism creates underwater sound	How this organism <i>makes and/or uses</i> underwater sound
Soldier Fish			
Bearded Seal			
Blue Whale			
Narwhal			

WATCHING THE VIDEO

Viewing Guide: Student Version

Anthropogenic Sounds

4. How does the Navy use underwater sound?
5. What is seismic surveying?
6. The narrator states that the most pervasive human sounds are caused by global commerce. Describe those sounds and why they are so wide-ranging.

Changing the Ocean Soundscape

7. What kinds of sounds do North Atlantic right whales create and why are those sounds so important?
8. What is masking? What is the effect of masking on the North Atlantic right whales?
9. How are scientists and engineers using the North Atlantic right whales' sounds to try to protect the population?

WATCHING THE VIDEO

Discussion Questions

Introduction

1. Why do so many animals use sound in the ocean?

Even clear water filters out light quickly, so vision only works well for close communication. Most of the ocean is opaque or dark, so vision is even more limited. (Many animals use bioluminescence where there isn't natural light but this also has a limited range.) Sound travels better (faster and farther) in water than air; therefore it's a good way to communicate. Some animals use smell, better described underwater as chemical communication, but it has limited utility and range.

Animal Sounds

2. Why do animals have such different ways of producing and using sound underwater?

The “solutions” an animal can evolve are often constrained by the mechanisms their evolutionary history and physiology give them as “options.” For example, fish physiology (gills, swim bladders) make it impossible for a fish to make sounds in the same way a seal does. They have no trachea to vibrate or larynx to force air through.

The way that animals will use sound influences and is influenced by the kind of sound they can produce. Fish in a school only need sounds to travel short distances, because the fish they communicate with are nearby. Whale sounds travel long distances, and it's no coincidence that mates are long distances away as well. Whales range over large areas, and without sounds that could travel long distances, they would be unlikely to be able to find and attract mates.

3. Name two similarities and two differences about the way shrimp and seals produce sound underwater.

Both use air to produce sound, though the seal's air remains trapped within its body, and the shrimp's cavitation “bubble” is produced outside its body. Both use parts of their body for sound production that have other primary uses: shrimp claw for food procurement, defense and display; seal airway for transporting air to the lungs when on the water's surface.

4. How does the narwhal (a “toothed whale”) use sound differently than the blue whale (a large baleen whale)?

The narwhal, like other toothed whales such as dolphins and orca, uses very high-frequency sounds for echolocation. High-frequency sounds travel short distances and “bump into” objects in their path—ideal for echolocation. Blue whales, like other large baleen whales, use very low-frequency sounds that travel long distances. Low-frequency sounds move through objects to travel long distances. (Think of the long range of AM radio on a cold, clear night.) The long range of the blue whale's call is essential for animals that could be separated by thousands of kilometers to find each other for reproduction.

Recently, scientists discovered an exception to the generalization above: humpback whales use sound to locate schools of fish. This is the first evidence of echolocation in baleen whales. Since they are using lower frequencies, they can't resolve small things like an individual fish, but they seem to be able to find big schools. It is likely that even blue whales use their sound to image their world. They may hear the sounds of their voices echoing against large objects, like the continental shelf or islands.



WATCHING THE VIDEO

Discussion Questions

Anthropogenic Sounds

5. **What are the costs and benefits of using sonar? What do intense, but intermittent sounds mean for animals nearby?**

Sonar provides a way to detect otherwise “invisible” objects, like modern submarines.

Previously, scientists thought that the intense sounds of sonar “deafened” animals. However, research has not upheld the hypothesis. Instead, research seems to show that the intense sounds can frighten animals, causing them to “run.” This causes trouble when they flee into bays and can end up “stranded” on beaches. In the case of beaked (or toothed) whales like dolphins, they may also come to the surface too quickly, and for too long, causing the nitrogen dissolved in their blood to form bubbles, giving them the “bends”—a painful, sometimes fatal, condition. In some cases, the sonar may sound like orca, the main predators of many of these species.

Please see the “How does sonar harm whales?” section of the included Interview with Chris Clark.

6. **How are the bubbles from a ship’s propeller related to the bubbles produced by a snapping shrimp?**

Both produce cavitation bubbles, which create sound when they eventually implode (collapse in on themselves).

7. **What are the costs and benefits of ship noise? Are there alternatives? What do long-lived sounds like this mean for animals nearby?**

Ship noise is inevitable from any propeller-driven vessel. But engines can be made quieter. For example, acoustically isolating engines from the hulls reduces amplification and reverberation of the sound. The cruise industry does this.

Even quieter engines (like those running on nuclear power) still produce cavitation bubbles from their propellers. However, quieter designs can reduce cavitation and increase efficiency. Therefore newer ships tend to be quieter. Older ships can be retrofitted, but it is expensive. Were there sufficient will, we could significantly reduce shipping noise. However, the reality is that we’d do a lot more by consuming less and buying from local producers.

The long-lived sounds are the equivalent of loud background noise for nearby animals—they make communication difficult and reduce the distance animal communication can travel.

Please see the last three sections of the Interview with Chris Clark included on the DVD. “What man-made sound is the noisiest?” “What effect does noise have on animals?” and “How can we reduce our acoustic impact?”

8. **What technological innovations or policy changes would you recommend to a group of politicians, businessmen, and fishermen seeking to help reduce human-produced aquatic noise in a city with a busy port and harbor?**

This question is intended to prompt students to devise creative solutions to human-produced noises. Answers will vary.

WATCHING THE VIDEO

Discussion Questions

Changing the Ocean Soundscape

9. What are the effects of sound-masking on animals?

The effective distances animals' communications can travel are greatly reduced. While the whales' sound isn't quieter, it cannot be heard as far away because it drops below the level of the background noise. By analogy, at a party your voice still travels throughout the room, but it is rapidly lost in the clamor.

This makes it more difficult for animals to find a mate, warn companions of predators, or coordinate actions. To compensate, animals can make themselves louder or get closer together—in much the same way people conversing at a loud party will do—but both of these solutions have energy costs and likely physiological constraints for the animals.

10. What are the costs and benefits of the Right Whale Listening Network? How would you investigate whether or not it is effective?

Benefits: protect a highly endangered species. There are only about 400 North Atlantic right whales remaining; the consequences of removing even one of them are substantial (especially a breeding female or a young animal).

Costs: monetary (buoys, equipment, maintenance, personnel, communications); slows ships down.

Answers will vary about investigating the effectiveness. One way would be with data about whales hit by shipping traffic before and after the monitoring system. (However, even with this data, critics and supporters could argue about other circumstances—in essence, reality is a poorly controlled “experiment!”)

11. The Right Whale Listening Network is set up in busy Massachusetts Bay. Who do you think the “stakeholders” are—people with interest in the system—and what differing priorities or concerns might they voice about the project?

This question is intended to encourage students to think about the variety of human interests that may impact such a project. Student responses to this answer will vary based upon their prior knowledge. Answers may include scientists, engineers, fishermen (commercial and recreational), boat captains, commercial shipping owners, harbor police, Coast Guard, environmental activists, animal rights' groups, or politicians.



WATCHING THE VIDEO

Video Table of Contents

Detailed Table of Contents for the *Sea of Sound* Video

Total Run Time [30:40]

Introduction [2:08]

Sound has played a central role in shaping the diversity of life in the ocean, but humans have altered the marine soundscape. Humans need to better understand sounds in the ocean.

Natural Sounds [3:34]

Shrimp snaps and bursting bubbles

The acoustic world beneath the surface of the ocean is very different from sounds at the coastline. Bubbles are the most ubiquitous source of sound in the ocean. The most widespread biological sounds are from snapping shrimp.

Drumming fish and singing whales communicate with sound

Many marine animals have evolved mechanisms for acoustic communication. Many species of fish make sounds to communicate, especially at spawning or mating times: black drum fish make pounding noises and male humpback whales sing.

The sounds of earthquakes, wind, waves, and rainstorms

Sound in the ocean is also created by natural phenomena such as seismic activity and weather. Wind and waves make bubbles; raindrops and lightning also produce sounds in the ocean.

The ocean's acoustic landscape

There is a diverse acoustic landscape in the ocean and our understanding of it is constantly developing. Understanding sound in the ocean is central to understanding the ocean itself.

Animal Sounds [11:40]

Mighty claws, tiny bubbles, and loud pops (snapping shrimp)

Snapping shrimp, the most widespread source of crackling sound in the oceans, live in reefs in tropical and temperate ocean waters. Snapping shrimp use cavitation—creating small bubbles that explode in the water and create pressure waves—to communicate, avoid predators, and kill prey.

Drummers on the reefs (soldierfish)

Fish use sound to send a variety of messages such as courtship, territoriality, and alarm; examples include chocolate dip chromis, Hawaiian dascyllus, and soldierfish. Soldierfish use sonic muscles connected to ribs, which are connected to their swim bladder to produce sound. Soldierfish sense sound in the swim bladder, which passes the signal to the otolith organs in their ears.

Showing off with eerie underwater calls (bearded seals)

Pinnipeds use their lungs and voice boxes to make sounds in air. Bearded seals live in the arctic and make long sounds underwater while holding their breath. The seals' elastic airway radiates sound like a fish's swim bladder, but the structure that creates sound is still unclear. The sound signals territoriality and social rank.



WATCHING THE VIDEO

Video Table of Contents

Making sounds that go the distance (blue whales)

Blue whales use ocean sound channels—formed by natural variations that concentrate sound in a relatively narrow layer of water—to communicate and find mates across thousands of kilometers. The speed of sound is determined by changes in water temperature and pressure. Sound travels farthest when it moves slowest.

Bouncing sound under arctic ice (narwhals)

Narwhals produce intense clicks from an organ in their foreheads. Echolocation, a type of active sonar, allows toothed whales to image the underwater environment and locate prey.

Anthropogenic Sounds [5:52]

Human echolocation: active sonar and the military

The ocean today is dominated by human sounds. Active sonar, a critical military tool, is the human version of echolocation. Types of military sonar include hull-mounted mid-frequency systems, lower-frequency towed arrays, and dipped systems. Sonar is very loud, but intermittent.

Picturing oceanic crust with seismic surveying

Geophysicists use seismic surveying, a type of sonar, to search for energy resources. Controlled explosions of compressed air make low-frequency pulses directed into the sea floor. Return echoes are captured by hydrophones. The technique reveals features in the earth's crust including lift and thrust zones.

The pervasive rumble of global commerce (shipping)

The most pervasive human sound in the ocean is created by global commerce. Huge tankers and container ships produce noise from engines and propellers. Propellers create cavitation bubbles. When one ship passes, it floods that area of the ocean with low-frequency sound lasting for hours.

Changing the Ocean Soundscape [6:07]

Masking noise: drowning out right whale calls with devastating results

Endangered North American right whales communicate using low frequencies. Social animals, the whales rely on sound traveling long distances for survival and reproduction. Today, the sounds from right whales are often masked by human sounds. Whale calls that once reached 2,000 square km today reach only 200 sq km. Whales are functionally blinded until nearby ships pass.

High-tech conservation: will a listening network help the right whales?

Scientists and engineers are working to find solutions to sound-masking. Busy shipping lanes crisscross the North Atlantic right whales' range; ships can hit whales. An early warning system in Massachusetts Bay uses computers on auto-detection buoys to record whales' primary contact call, the upcall. The system notifies ship captains to slow down when right whales are in the area.

Conclusion [1:18]



WATCHING THE VIDEO

Interview Table of Contents

Video Table of Contents: Interview with Dr. Christopher Clark

Total Run Time [20:44]

The interview is focused around a set of key questions:

Animal Sound [10:28]

What ocean animals use sound?

Most ocean animals make sound and have some way of “listening.” Many have evolved a way of communicating.

How do animals make and hear sound underwater?

Marine animals are highly adapted to making and hearing sounds—the auditory cortex in the brains of whales and dolphins is proportionally 10x larger than ours. There are all sorts of “inventions” used by animals to make sound; fish vibrate swim bladders, grind teeth, rub gills, and use other unknown mechanisms.

How do you discover which animals are making which sound?

Whales don’t open their mouths or release bubbles, so how do you know who is making sounds? There is much we do not know about the “inventory” of ocean sounds.

Why do so many animals use sound?

Animals will be most successful if they can hear and make sounds. Sight and smell (pheromones) are not effective over long distances, but sound travels well. The blue whale can barely see its tail, but it can hear another blue whale hundreds of kilometers away. The lower the frequency of sound, the farther it can travel.

How do large whales make long-distance calls?

Whale sounds are adapted to take advantage of the long-range communication channel. They communicate with one another over an entire ocean basin.

How do marine mammals “see” with sound?

We see in colors, brightness, textures, and in our “mind’s eye”—all these concepts translate to sound. Dolphins put out a pulse of sound like a beam of light. It reflects off objects as light does, and dolphins can hear the reflections. They visualize their environment with their voices.

Anthropogenic Sound [10:16]

How does sonar harm whales?

Mid-frequency Navy sonar sounds like killer whales. Animals likely are having a behavioral response—dolphins come to the surface to get air, and then they try to escape. Often they run into the beach. Some humpbacks challenge the sound, others move away. Sonar isn’t killing the whales directly, but instead puts them in a state where the probability of trouble is much higher.



WATCHING THE VIDEO

Interview Table of Contents

What is the impact of sonic surveys?

Sonic surveys for oil exploration create extremely loud explosions every 10 seconds for weeks and months at a time. Communication between animals becomes very difficult.

What man-made sound is the noisiest?

The major source of noise in the ocean is shipping. More than 90% of the world's commerce travels on ships. There has been a 10-fold increase in noise every decade. In the lifetime of a large whale, some of its environment has 1,000 times the noise there was 40 years ago. The “acoustic smog” is effectively reducing the listening range of an animal to 10% of what it was 40 years ago.

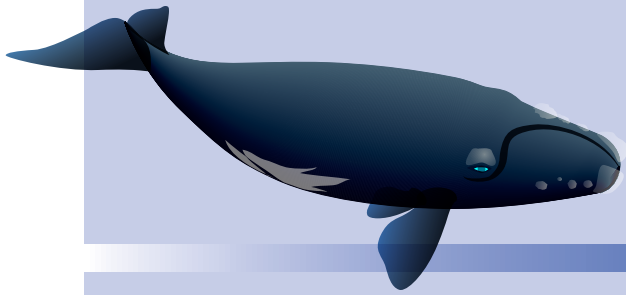
What effect does noise have on animals?

The “acoustic smog” has raised the background noise level. Ship noise can be heard long distances, just like blue whale voices. We humans are doing unhealthy things in the marine neighborhood. And ultimately that will affect us because we need the oceans.

How can we reduce our acoustic impact?

We know that we can build very quiet ships. For example, the cruise industry builds ships that are three orders of magnitude quieter than regular ships. The oil exploration companies are looking at ways to be quieter and less intrusive. One way is to avoid the neighborhood when animals are there—change the timing. To know that, we need researchers to listen to the ocean and figure out when is the best time to survey.





SONAR DEBATE

Teacher Notes

Before You Start

Time Frame

- Watch *Sea of Sound* DVD (30 minutes). Emphasize “Anthropogenic Sound” section (5:52).
- Preparation for debate: one or two 45-minute class periods, if preparing in class.
- Debate: one 45-minute class period.

Grade Level: 8–12

Materials Needed

- *Sea of Sound* DVD
- DVD player with television or projection
- Student **Debate: Sonar Handout**

Getting Ready

- Watch *Sea of Sound* video.
- Choose debate format. Assign roles.
- Reproduce student **Debate: Sonar Handout**.

Overview

Do the benefits of using sonar outweigh the costs? As *Sea of Sound* explains, the U.S. Navy uses sonar as part of its operations. However, organizations such as the National Resources Defense Council and The Humane Society argue that sonar use is detrimental to some marine organisms.

Learning Objectives

Students will:

- know what sonar is, how humans use it in the ocean, and what impacts it may have on marine mammals;
- understand that there are significant arguments about the value and use of sonar in the ocean;
- use facts and data to support their arguments and conclusions about sonar use in the oceans.

Activity Overview

Students:

- watch *Sea of Sound* video;
- do research and prepare their “arguments”;
- hold in class debate;
- write opinion papers using arguments and evidence from class debate.

Prior knowledge

Before beginning this set of activities, students should have general background knowledge on the following:

- **Sonar:** a system for measuring or detecting underwater objects using sound waves. When sounds are transmitted and the reflected signals are measured, this is called active sonar. In contrast, passive sonar systems are listen-only.
- **Masking:** when one sound makes it more difficult to hear another sound.
- **Stranding:** when a marine mammal, such as a dolphin, washes up on a beach, either dead or alive.
- **Cetacean:** large aquatic mammal with no hind limbs (ex: whales, porpoises, narwhals) commonly “whales and dolphins.”
- **NGO:** a non-governmental, not-for-profit organization, like The Nature Conservancy or The Humane Society.

Teaching Tips

- There are many successful formats for in-class debates. Two that would work well are:

- Opposing counsel: set up the debate like a courtroom with a judge (likely you) who moderates the proceedings. Under this model you can appoint lead counsel for each side, whose job is to coordinate the arguments. This model can include opening and closing arguments.
- Open forum: you open the debate by asking the question and then let student momentum carry it from there. A score sheet is useful to keep track of which students have commented, and how compelling, well-argued, and evidence-based their arguments have been.
- Evaluation: Students write a short opinion paper after the debate, synthesizing facts and arguments and presenting their own reasoned, well-supported opinions. This is an opportunity to emphasize the use of evidence and data in supporting argument.

Resources and Extension Activities

- DOSITS “Thinking Inside the Box” Activity: classroom-ready activity in which students simulate sonar use for mapping a model of the ocean floor (built in a copy-paper box). Students use Excel and data in this hands-on activity. (Find it at <http://dosits.org> in the Resources/Teachers section, Classroom Activities/Thinking Inside the Box.)
- DOSITS (<http://dosits.org>) has other teacher resources about People and Sound in the Sea, the Science of Sound in the Sea, and a Technology Gallery, as well as detailed tutorials about the Effects of Sound, a Science Tutorial and a Technology Tutorial. There is also a tutorial focused on sonar.

National Science Education Standards

PHYSICAL SCIENCE: Interactions of Energy and Matter

LIFE SCIENCE: Interdependence of Organisms; Behavior of Organisms

SCIENCE AND TECHNOLOGY: Understanding About Science & Technology

PERSONAL AND SOCIAL PERSPECTIVES: Natural Resources; Environmental Quality; Science and Technology in Local, National & Global Challenges

Ocean Literacy Principles

For detailed descriptions, see pages 3–4 of this guide or the framework diagram at oceanliteracy.wp2.coexploration.org.

The ocean supports a great diversity of life and ecosystems. (5)

- Grades 6–8—B5 and B9
- Grades 9–12—C27 and C28

The ocean and humans are inextricably linked. (6)

- Grades 6–8—D18, E1, and E6
- Grades 9–12—D11, D12, and E6

Standards-alignment matrices are available on the DVD or at seaofsound.org.

Acknowledgments

By Elizabeth Rice, Ph.D. and Susan Dodge, M.S.Ed., Creative Curriculum, for *Sea of Sound*. Edited by Marc Dantzker. Designed by Joanne Avila. Adapted, by permission, from *Saving Seas: Navy Sonar and its impact on whales and their kin*. http://www.entanglements.net/saving_seas/topic_pages/sonar.htm. If reproducing this version, please cite *Sea of Sound* as the source and provide the URL: seaofsound.org.

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Student Handout

The U.S. Navy uses sonar to detect submarines and other potential threats in the ocean. Low and mid-frequency sounds travel farther in water than in air so sounds stay louder farther from their sources than they would in air. The Navy uses sonar systems that generate very loud sounds at a variety of frequencies. Some anecdotal and forensic evidence suggests that some types of sonar can result in the deaths of some whales and dolphins. The mechanism is not clearly understood, but evidence is pointing to behavioral responses to the loud sounds. Navy officials have acknowledged that sonar can be a problem for some whales and have begun tests to better determine its impacts, but they are reluctant to abandon or strictly curtail the use and development of sonar arrays, citing national security concerns.

Do the benefits of using sonar outweigh the costs?

Potential Arguments

➤ Anti-sonar

- Sound travels farther in water than air, so the range of potential impact of sounds is higher underwater than it is above the surface.
- What are effects of sonar on marine mammals? Use data to support.
- Some sonar-testing sites are near marine mammal sanctuaries and rich ecosystems. What effect does this have? Use data and maps to illustrate.
- The Navy isn't required to file environmental impact statements for reasons of national security. However, lawsuits from animal rights organizations have forced the Navy and industry to negotiate.
- Current research suggests a relationship between marine mammal strandings and mid-frequency sonar. More research about the precise impacts of sonar is needed.
- A potential compromise might be to find suitable locations or times to test and use sonar that will not impact whales.

➤ Pro-sonar

- What is sonar? How does it work? Why does the Navy need it?
- The Navy needs to have ongoing training on sonar operations in flexible locations.
- There is scientific uncertainty about impacts of sonar on marine mammals. The main problem for whales may be displacement, disruption, and stress, rather than death.
- Sonar noise is only one of many ocean noise issues impacting whales and other marine life.
- Some environmental groups and industry representatives may be perceived to gain by prolonging the conflict and stalemate.

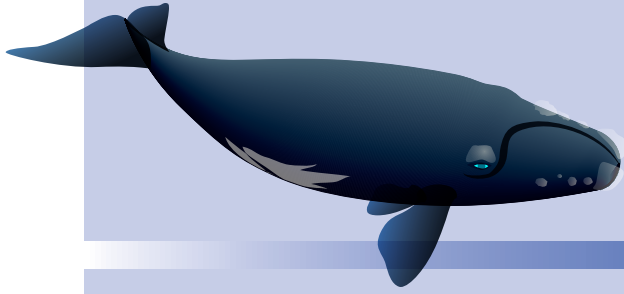
DEBATE: SONAR

Student Handout

Resources

- The *U.S. Marine Mammal Commission's* (<http://www.mmc.gov>) report titled *Advisory Committee on Acoustic Impacts on Marine Mammals Report to the Marine Mammal Commission* released in February 2006. (<http://goo.gl/XLVB4>) Read at least the “Process Summary,” pages 1–3, about the lack of consensus on the committee and the resulting set of “non-consensus statements” produced by caucuses among the committee members.
- “Panel quits in row over sonar damage” in *Nature* by Rex Dalton, January 24, 2006, offers a brief-but-meaty account of the breakdown of the Marine Mammal Commission’s Advisory Committee on Acoustic Impacts on Marine Mammals (requires subscription). (<http://bit.ly/dKhlWg>)
- The *U.S. Navy's* website includes summaries of the Navy’s position on the issue and their research agenda. (<http://goo.gl/zcD95>)
- The *Natural Resources Defense Council's* Webpage on Whales and Sonar (<http://bit.ly/fXpeGZ>) includes statements about NRDC’s position and links to reports, including Michael Jasny, J. Reynolds, C. Horowitz, and A. Wetzler’s report *Sounding the Depths II: The Rising Toll of Sonar, Shipping and Industrial Ocean Noise on Marine Life*. Natural Resources Defense Council, 2005. Read at least the “Executive Summary,” p. iv–vii. (<http://bit.ly/gZkg9e>)
- The *U.S. Navy's Official website for the Undersea Warfare Training Range* has information about a sonar array that the Navy plans to build along the Atlantic coast of the United States. The project overview and fact sheet sections are particularly useful for understanding the proposed project and the Environmental Impact Statement process. (<http://bit.ly/dMzLtO>)
- The *Humane Society of the United States web page on Noise Pollution and Acoustic Harassment* offers a brief outline of HSUS’s position on sonar and links to press releases and updates. (<http://bit.ly/fGccBd>)
- “Making Sense of Ocean Noise” is a short article on Peter Tyack’s congressional testimony regarding the Marine Mammal Protection Act from *Woods Hole Currents*, Winter 2003. If you want to delve deeper, a link in the lower left takes you to the full text of his testimony. (<http://bit.ly/hH47gs>)

SEA OF SOUND



CONGRESSIONAL HEARING

Teacher Notes

Before You Start

Time Frame

- Watch *Sea of Sound* DVD (30 minutes). Emphasize the sections “Anthropogenic Sound” (5:52) and particularly “Changing the Ocean Soundscape” (6:07).
- Hearing: two 45-minute class periods.

Grade Level: 8–12

Materials Needed

- *Sea of Sound* DVD
- DVD player with television or projection
- Student **Congressional Hearing Handout**

Getting Ready

- Watch *Sea of Sound* video.
- Assign roles for Congressional Hearing.
- Reproduce student **Congressional Hearing: Right Whale Listening Network Handout**.

Overview

The North Atlantic right whale is one of the most endangered species on our planet. With fewer than 400 individuals of this long-lived species remaining in the wild, the loss of any individual whale—especially calves and reproductive females—greatly affects the future of the species. The whales travel the east coast of North America, including many heavily trafficked ports. The right whale feeds by scooping large mouthfuls of water near the ocean’s surface and filtering its food through its baleen plates. Its surface feeding behavior and habitat range place it in the direct path of ship traffic in busy harbors like Boston, Massachusetts.

Scientists and whale advocates have devised a way to use the whale’s own sound to protect it. Computers using underwater microphones, called hydrophones, constantly monitor the ocean. They automatically detect and record one distinctive type of right whale call. A team of acoustic experts verifies the call. Then the system automatically transmits the whale’s location back to ship captains in the busy Massachusetts Bay. Captains can reduce ship speeds, greatly reducing the potential for hitting a whale. The system is called The Right Whale Listening Network and you can monitor it at the website listenforwhales.org.

Who should fund The Right Whale Listening Network?

Taxpayers? Shipping companies? Environmental groups?

Student Activity

Hold an informational hearing for the U.S. Senate Committee on Environment and Public Works,* where students represent diverse viewpoints—such as advocates for whales, shipping captains, scientists explaining technical capabilities, or politicians concerned with costs. Students present perspectives more complex than simply pro or con.

* Committee website (bit.ly/fNBX33)

Learning Objectives

Students will:

- know how whales use sound in the ocean, how human activities impact whale communication, and that different stakeholders have different perspectives;
- understand the costs and benefits of protecting endangered species;
- be able to argue a particular viewpoint using fact and data to support their arguments.

Activity Overview

Students:

- watch *Sea of Sound* video;
- do research and prepare their “testimony”;
- hold hearing in class;
- write opinion papers using arguments and evidence from class hearing.

Prior knowledge

- **Endangered species:** a group at risk of extinction because its population is so small.
- **Masking:** when one sound covers another sound.
- **Hydrophone:** an underwater microphone.

Teaching Tips

- You may wish to have students work from an electronic version of the handout, because the URLs listed in the Student Handout below are long. They are also available online at: seaofsound.org.
- Students could work in teams to research and prepare testimony.
- Potential stakeholders include: scientists, engineers, fishermen (commercial and recreational), boat captains, commercial shipping owners, harbor police, Coast Guard, environmental activists, animal rights groups, or politicians.
- Testifying “experts” should have a short time limit (~4 minutes) and could be required to use visual aids and data to present their cases.
- Testifying experts could also realistically be asked to answer questions from “the committee,” whether this is the entire class, or a designated subset of students.
- Additional role of Committee Chairperson (who runs the hearing) can be assigned, though you may wish to retain control of this aspect of the activity.
- You may also want to assign several coordinators who could organize statements for a group of stakeholders to minimize repetition. These coordinators might (or might not) be responsible for cross-examination of testifying “experts.”
- Evaluation: Students write a short opinion paper after the hearing, synthesizing facts and arguments and presenting their own reasoned, well-supported opinions. This is an opportunity to emphasize the use of evidence and data in supporting arguments.



Resources and Extension Activities

- The *Sea of Sound* DVD has a webquest using the listenforwhales.org website, as well as a data interpretation exercise, and a fact sheet about the North Atlantic right whale.
- The *Sea of Sound* DVD also contains a 20-minute interview with Senior Scientific Advisor, Dr. Christopher Clark. Relevant sections include information about how whales use sound, the effects of noise on whales, the noise contributions of shipping, and what we can do to improve the situation.
- The Discovery of Sound in the Seas (DOSITS) website has classroom-ready hands-on activities such as how to build an inexpensive hydrophone and an activity using sound to track whales in the oceans. (dosits.org/resources)

National Science Education Standards

UNIFYING CONCEPTS AND PROCESSES: Change, constancy and measurement; Evolution and Equilibrium

PHYSICAL SCIENCE: Interactions of Energy and Matter

LIFE SCIENCE: Biological Evolution; Interdependence of Organisms; Behavior of Organisms

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- Grades 9–12—C27 and C28

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- Grades 6–8—D18, E1 and E6
- Grades 9–12—D11, D12 and E6

Standards-alignment matrices are available on the DVD or at seaofsound.org.

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Student Handout

Mock Congressional Hearing: The Right Whale Listening Network

The North Atlantic right whale is one of the most endangered species on our planet. With fewer than 400 individuals of this long-lived species remaining in the wild, the loss of any individual whale—especially calves and reproductive females—greatly affects the future of the species. The whales travel the east coast of North America, including many heavily trafficked ports. The right whale feeds by scooping large mouthfuls of water near the ocean's surface and filtering its food through its baleen plates. Its surface feeding behavior and habitat range place it in the direct path of ship traffic in busy harbors like Boston, Massachusetts.

Scientists and whale advocates have devised a way to use the whale's own sound to protect it. Computers using underwater microphones, called hydrophones, constantly monitor the ocean. They automatically detect and record one distinctive type of right whale call. A team of acoustic experts verifies the call. Then the system automatically transmits the whale's location back to ship captains in the busy Massachusetts Bay. Captains can reduce ship speeds, greatly reducing the potential for hitting a whale. The system is called The Right Whale Listening Network and you can monitor it at the website listenforwhales.org.

Who should fund The Right Whale Listening Network?

Taxpayers? Shipping companies? Environmental groups?

Potential Stakeholders

- **Technical:** How does the system work?
 - Biologists: How do right whales use sound?
 - Physicists: How does sound move in the ocean? Why is this important for the whales?
 - Bioacoustics experts: How can you use sound to protect whales? How does The Right Whale Listening Network work? What are the challenges of the system?
 - Engineers: What are the challenges of recording sound in the ocean? What is unique about the buoy system used in the Right Whale Listening Network?
- **Animal Advocates:** How does the system protect right whales? Why do they need protection? What happens to a whale that is struck? Does changing boat speed affect a whale's chance for survival?
 - Conservation biologists: How many right whales are left? Why are there so few? How does their biology (behavior, range, and life history) affect their chances for recovery?
 - Environmental activists: How do human-derived sound and human-created threats affect right whales and their chances for recovery?
 - Animal rights groups: How are whales affected by humans?
 - Lawyer: How does the Endangered Species Act apply?
 - Wildlife biologists: Does changing a ship's speed change a whale's chance of survival? How and why?
- **Other users of the Bay:** What effect does the system have on others?
 - Ship captains: When the warning system sounds, what are captains supposed to do? What do they actually do? Why?

CONGRESSIONAL HEARING

Student Handout

- Fishermen (commercial and recreational): Are fishing boats required by law to slow down if a right whale is nearby? What effect does slowing down have for a fisherman? What are the costs of going more slowly?
 - Commercial shipping owners: How much ship traffic goes through the Bay? What are the costs of going more slowly? What are the costs (monetary, political, etc.) of a ship hitting an endangered whale?
 - Gas terminal managers and ship captains: What role did the gas terminal play in developing and maintaining the system? What are the costs and benefits of the system for the gas terminal? What are the costs (monetary, political, etc.) of a ship hitting an endangered whale?
 - Harbor police/Coast Guard: Is there additional enforcement associated with the warning system? Who is responsible? Who bears the costs? What happens to those who don't comply?
- **Government:** What are the costs of the system?
- Gas terminal owners: Who currently pays for the system?
 - Politicians: Who benefits from such a system? Can we afford such a system?
 - Congressional Budget Office: What might such a system cost?

Resources

Right Whale Listening Network—listenforwhales.org

- North Atlantic right whale background—<http://goo.gl/usKyW>
- Threats to whales—<http://goo.gl/3C49m>
- How does the Right Whale Listening Network work?—<http://goo.gl/7jfc2>
- How do the buoys work?—<http://goo.gl/6xHFr>
- How are boat captains warned?—<http://goo.gl/l7yOL>

The North Atlantic Right Whale Consortium—rightwhaleweb.org

- Right Whale News—bit.ly/gIaBBs

NOAA Fisheries: Office of Protected Resources—nmfs.noaa.gov/pr/

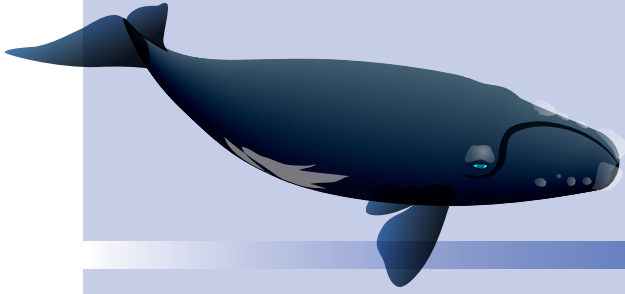
- North Atlantic right whale background—bit.ly/i4eORI
- The Endangered Species Act—bit.ly/fiDpVy
- Rules for boat speeds—bit.ly/ghPKbA

John Kerry introduces bill to reduce ship strikes to whales—bit.ly/dTI2p8

News articles

- *Vineyard Gazette*, “Law to Protect Right Whales May Hamper Ferry Operations”—bit.ly/i9etLU
- *Washington Post*, “OMB Hits the Brakes on Right Whale Rule”—wapo.st/iiFhgo
- Whale in the Cape Cod Canal—wp.me/paGo0-lbw
- *Gloucester Times*, “System uses sound to find whales, avoid ship strikes”—bit.ly/gx7Q4v
- WHOI-*Oceanus Magazine*, Excelerate Energy, Cost of system and buoy design—bit.ly/i0TTOR
- *The Boston Globe*, “Undersea detection system helps to guard against collision with ships—bit.ly/iaVdOf
- Perspectives from boat captains, fishermen etc. may be found in articles and opinion pieces from local papers around the Bay.

SEA OF SOUND



LISTEN FOR WHALES

Teacher Notes

Before You Start

Time Frame

- Watch *Sea of Sound* DVD (30 minutes). Emphasize “Anthropogenic Sounds” chapter and particularly the section “Changing the Ocean Soundscape.”
- **Right Whale Information Sheet** and **Right Whale Data Activity**: two 40-minute periods plus 10 minutes per day for 2 weeks for additional data collection.
- **Listen for Whales Webquest**: one 40-minute period.
- Teacher prep time: Around one hour for the entire unit.
- Watch Interview DVD (20 min). See teaching tips below for sections to emphasize.

Grade Level: 10–11

Appropriate for grades 6–12, with extension activities.

Materials Needed

- Computers with web browsing capability.
- **Right Whale Information Sheet** and **Questions**
- **Listen for Whales Webquest**
- **Right Whale Data Activity**

Goals

The goals of this activity are: 1) to understand the biology, behavior and ecology of the endangered North Atlantic right whale; 2) to understand The Right Whale Listening Network in Massachusetts Bay; and 3) to interpret data, make graphs and infer life history traits from authentic monitoring data.

Learning Objectives

Students will be able to:

- describe general features and characteristics of right whales;
- describe several threats to right whales;
- analyze and interpret a spectrogram;
- identify and analyze various right whale calls using a spectrogram;
- analyze a sound detection map and describe how it can be used to protect and preserve right whales;
- analyze data on right whale calls and make inferences about the whales based on the data;
- collect and analyze real time data to make conclusions about right whale movement in Massachusetts Bay.

Prior knowledge

Before beginning this set of activities, students should have familiarity with the following:

- **Sound** is a wave. It travels faster and farther in water than it does in air.
- **Endangered species**: a group of organisms at risk of extinction because the population is so small.
- **Hydrophone**: an underwater microphone

Teaching Tips

These activities are modular, so you can mix-and-match to create a combination that fits your classroom.

You may wish to use the *Sea of Sound* video as an

introduction to the unit. Note that the DVD contains a **Viewing Guide**, **Teacher Notes**, and a **Matrix** aligning the video content with national middle and high school standards.

Listen For Whales Webquest Activity

- Consider giving students an overview of the website before starting the webquest. Showing students how to navigate through the website will make the webquest run smoothly.
- To introduce the webquest it may be helpful to watch and discuss some of the video clips on the listenforwhales.org website as a class. For example, the clip “Life as a Right Whale” provides a general introduction to North Atlantic right whales. This may spark student interest and give them a scaffold for the webquest.

Right Whale Data Activity and Right Whale Information Sheet

- The data exercise and information sheet are designed to go together. The information sheet provides all the supplemental information students will need to understand the right whales’ seasonal behavior.
- You may want to review how to create a graph before beginning the data exercise.
- You may find it useful to allow students to share their ideas and work in collaborative pairs for this exercise.
- An extension activity (see below) is available for this exercise.

Interview with Dr. Christopher Clark

- The DVD contains a 20 min interview. (See page 16 for details.) You can access each question directly from the “Interview” menu on the DVD. For this activity, play or emphasize his answers to the following questions:
 - What ocean animals use sound?
 - How do animals make and hear sound underwater?
 - What man-made sound is the noisiest?
 - What effect does noise have on animals?

Extensions

- The DVD contains resources for holding an in-class congressional hearing about whether or not to fund The Right Whale Listening Network, from which this data is derived.
- Data extension: Compare whale detection by sound (as in the data activity above) to whale detection by visual sighting. A data table is in **Data Activity Extension** at the end of these teacher notes. The entire report on aerial sightings is available from: <http://goo.gl/pdfQR>.
- Other extension activities may also be developed by accessing dosits.org, which has classroom ready activities based on sound in marine environments.

Resources

- This activity utilizes resources available at listenforwhales.org.
- The North Atlantic Right Whale Catalog contains photo identifications of all known right whales. (rwcatalog.neaq.org/)
- The Northeast U.S. Right Whale Sighting Advisory System gives the latest whale warnings issued to ships. (<http://www.nefsc.noaa.gov/psb/surveys/>)



- Data from auto-detection buoys like those used in this exercise were used to shift the shipping lanes in Boston's harbor to protect the right whales. (<http://goo.gl/8hwC9>)
- A gallery of whale sounds (and other marine mammals) is available from the University of Rhode Island. (<http://www.dosits.org/audio/marinemammals/>)
- The DOSITS website has classroom-ready hands-on activities such as how to build an inexpensive hydrophone and an activity using sound to track whales in the oceans. The DOSITS site also has tutorials and resources for understanding sound in the oceans, how animals use sound, and the physics of sound. (dosits.org/resources)

National Science Education Standards

UNIFYING CONCEPTS AND PROCESSES: Systems, Order and Organization; Evidence, Models, and Explanation; Change, Constancy, and Measurement; Evolution and Equilibrium

SCIENCE AS INQUIRY: Abilities Necessary to Do Scientific Inquiry; Understanding About Scientific Inquiry

LIFE SCIENCE: Interdependence of Organisms; Behavior of Organisms

SCIENCE AND TECHNOLOGY: Understanding About Science & Technology

PERSONAL AND SOCIAL PERSPECTIVES: Population Growth; Environmental Quality; Natural and Human induced hazards.

Ocean Literacy Principles

For detailed descriptions, see pages 3–4 of this guide or the framework diagram at oceanliteracy.wp2.coexploration.org.

The ocean supports a great diversity of life and ecosystems (5).

- Grades 6–8—B5 and B9
- Grades 9–12—C27 and C28

The ocean and humans are inextricably interconnected (6).

- Grades 6–8—D18, E1, and E6
- Grades 9–12—D11, D12, and E6

Standards-alignment matrices are available on the DVD or at seaofsound.org.

Acknowledgments

By Amanda Wolfgang M.S. Ed. and Elizabeth Rice, Ph.D., Creative Curriculum, for *Sea of Sound*. Art by Daniel Deibler. Edited by Marc Dantzker. Designed by Joanne Avila. The Right Whale Information sheet is reproduced with permission from NOAA Fisheries, Office of Protected Resources. If reproducing this version, please cite *Sea of Sound* as the source and provide the following URL: seaofsound.org.

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LISTEN FOR WHALES

Right Whale Information

North Atlantic Right Whales (*Eubalaena glacialis*)

Species Description

Right whales are large baleen whales. Adults are generally between 45 and 55 feet (13.7–16.7 m) in length and can weigh up to 70 tons (140,000 lbs; 63,500 kg). Females are larger than males. Calves are 13–15 feet (4–4.5 m) in length at birth.

Distinguishing features for right whales include a stocky body, generally black coloration (although some individuals have white patches on their undersides), lack of a dorsal fin, a large head (about 1/4 of the body length), strongly bowed margin of the lower lip, and callosities (raised patches of roughened skin) on the head region. Two rows of long (up to eight feet in length) dark baleen plates hang from the upper jaw, with about 225 plates on each side. The tail is broad, deeply notched, and all black with a smooth trailing edge.

Females give birth to their first calf at an average age of 9–10 years. Gestation lasts approximately one year. Calves are usually weaned toward the end of their first year. In the coastal waters off Georgia and northern Florida, calving occurs from December through March.

Using cross-sections of teeth is one way to age mammals. However, right whales have no teeth. Therefore, ear bones and, in some cases, eye lenses can be used to estimate age in right whales after they have died. It is believed that right whales live at least 50 years, but there is little data on the longevity of right whales. There are indications that closely related species may live more than 100 years.

Right whales feed from spring to fall, and also in winter in certain areas. The primary food

sources are zooplankton, including copepods, euphausiids, and cyprids. Unlike other baleen whales, right whales are skimmers: they move through a patch of zooplankton with their mouths open to filter out prey through their baleen plates.



NOAA FISHERIES

Taxonomy

- Kingdom: Animalia
- Phylum: Chordata
- Class: Mammalia
- Order: Cetacea
- Family: Balaenidae
- Genus: *Eubalaena*
- Species: *glacialis*

Habitat

Most known right whale nursery areas are in shallow, coastal waters. The International Whaling Commission has identified four categories of right whale habitats:

1. Feeding—areas with copepod and krill densities that routinely elicit feeding behavior and are visited seasonally
2. Calving—areas routinely used for calving and neonatal nursing
3. Nursery—aggregation area(s) where nursing females feed and suckle
4. Breeding—locations where mating behavior leading to conception occurs; breeding areas are not known for supporting a long-term population

Right whales have occurred historically in all the world's oceans from temperate to subpolar latitudes. They primarily occur in coastal or shelf waters, although movements over deep waters are known. For much of the year, their distribution is strongly correlated to the distribution of their prey. During winter, right whales occur in lower latitudes and coastal waters where calving takes place. However, the whereabouts of much of the population during

LISTEN FOR WHALES

Right Whale Information

winter remains unknown. Right whales migrate to higher latitudes during spring and summer.

Distribution

North Atlantic right whales inhabit the Atlantic Ocean, particularly between 20° and 60° latitude. The majority of individuals in the western North Atlantic population range from wintering and calving areas in coastal waters off the southeastern United States to summer feeding and nursery grounds in New England waters and north to the Bay of Fundy and Scotian Shelf. Five areas of “high use” were identified by NMFS in 1991 and are still key habitat areas for right whales:

1. Coastal Florida and Georgia
2. Great South Channel
3. Massachusetts Bay and Cape Cod Bay
4. Bay of Fundy
5. Scotian Shelf



North Atlantic right whale range

NOAA FISHERIES

The eastern North Atlantic population may originally have migrated along the coast from northern Europe to the northwest coast of Africa. Historic records suggest that animals were heavily exploited by whalers from the Bay of Biscay (off southern Europe) and Cintra Bay (off the northwestern coast of Africa), as well as off coastal Iceland and the British Isles. During the

early to mid 1900s, right whales were intensely harvested in the Shetlands, Hebrides, and Ireland. Recent surveys suggest right whales no longer frequent Cintra Bay or northern European waters. Due to a lack of sightings, current distribution and migration patterns of the eastern North Atlantic right whale population are unknown.

Population Trends

It is believed the western North Atlantic population numbers only about 300-400 individual right whales. Recent analysis of sightings data suggests a slight growth in the population size, however, North Atlantic right whales remain critically endangered.

Although precise estimates of abundance are not available for eastern North Atlantic right whales, the population is nearly extinct, probably only numbering in the low tens of animals. It is unclear whether right whales found in the eastern North Atlantic represent a “relict” population or whether all or some of these right whales are individuals from the known western North Atlantic population.

Threats

Ship collisions and entanglement in fishing gear are the most common human causes of serious injury and mortality among western North Atlantic right whales. Additional threats may include habitat degradation, contaminants, climate and ecosystem change, and predators such as large sharks and killer whales. Disturbance from such activities as whale-watching and noise from industrial activities may also affect the population.

Conservation Efforts

Right whales were first protected by the 1931 Convention for the Regulation of Whaling, which took effect in 1935. However, neither Japan nor the Soviet Union signed this agreement, so they were theoretically free to kill right whales. In 1949, the International Convention for the Regulation of Whaling protected right whales from commercial whaling.



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Right Whale Information

In U.S. waters, right whales were determined to be in danger of extinction in all or a significant portion of their range due to commercial over-utilization. As a result, they were listed as endangered under the Endangered Species Conservation Act in June 1970, the precursor to the Endangered Species Act (ESA). The species was subsequently listed as endangered under the ESA in 1973. In the same year, the species was designated as depleted under the Marine Mammal Protection Act (MMPA). In 2008, NMFS listed the endangered northern right whale (*Eubalaena spp.*) as two separate, endangered species: the North Pacific right whale (*E. japonica*) and North Atlantic right whale (*E. glacialis*).

NOAA Fisheries Service has taken both regulatory and non-regulatory steps to reduce the threat of ship collisions, including:

- Mandatory vessel speed restrictions in Seasonal Management Areas
- Voluntary speed reductions in Dynamic Management Areas and a seasonal Area To Be Avoided
- Recommended shipping routes
- Modification of international shipping lanes
- Aircraft surveys and right whale alerts
- Ship speed advisories
- Mandatory ship reporting systems
- Outreach and education
- Stranding response

To address entanglement in fishing gear, NOAA established the Atlantic Large Whale Take Reduction Team. This team developed a plan to reduce the incidental serious injury and mortality of right, humpback, fin, and minke whales in the South Atlantic shark gillnet fishery, the Gulf of Maine and Mid-Atlantic lobster trap/pot fishery, the Mid-Atlantic gillnet fishery, and the Gulf of Maine sink gillnet fishery.

Federal law and Massachusetts state law prohibit coming within 500 yards of a right whale unless

permitted by NMFS or unless one of the limited exemptions applies.

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Did You Know?

- Right whales are the rarest of all large whale species and among the rarest of all marine mammal species.
- There are only 300–400 right whales left in the North Atlantic.
- Adult right whales are about 50 feet (15m) long, and can weigh up to 70 tons (140,000 lbs; 63,500 kg).
- Right whales were severely depleted by commercial whaling; they have a thick layer of blubber, so they float when dead, making them an easy—and profitable—species for early whalers.



LISTEN FOR WHALES

Right Whale Information—Questions: Teacher Version

North Atlantic Right Whales (*Eubalaena glacialis*)

Introduction and Learning Goals

North Atlantic right whales are one of the most endangered marine species on earth. In this activity you will explore the life history of the North Atlantic right whale, and learn about its distinctive characteristics.



Procedure:

Read the supplemental information sheet and answer the following questions.

Species Description:

1. Describe the distinctive features that separate right whales from other whales.

Distinguishing features for right whales include a stocky body, generally black coloration (although some individuals have white patches on their undersides), lack of a dorsal fin, a large head (about 1/4 of the body length), strongly bowed margin of the lower lip, and callosities (raised patches of roughened skin) on the head region. Two rows of long (up to eight feet in length) dark baleen plates hang from the upper jaw, with about 225 plates on each side. The tail is broad, deeply notched, and all black with a smooth trailing edge.

2. How long do right whales live? How can one determine the age of a right whale?

Using cross-sections of teeth is one way to age mammals. However, right whales have no teeth. Therefore, ear bones and, in some cases, eye lenses can be used to estimate age in right whales after they have died. Right whales are believed to live at least 50 years, but there is little data on the longevity of right whales. Closely related species may live more than 100 years.

3. How long is a right whale's gestation period? When and where does calving usually occur?

Females give birth to their first calf at an average age of 9-10 years. Gestation lasts approximately one year. Calves are usually weaned toward the end of their first year. Calving occurs in the coastal waters off Georgia and northern Florida, from December through March.

4. How do right whales feed and what do they typically feed on?

Right whales feed from spring to fall, and also in winter in certain areas. The primary food sources are zooplankton, including copepods, euphausiids, and cyprids. Unlike other baleen whales, right whales are skimmers meaning they move through a patch of zooplankton with their mouths open to filter out prey through their baleen plates. Right whales typically feed close to the surface, which makes them more vulnerable to ship strikes.

LISTEN FOR WHALES

Right Whale Information—Questions: Teacher Version

Habitat

5. What are the four major right whale habitats and what distinguishes one from another? Be sure to use the map to specifically locate each major habitat.

Feeding—areas with copepod and krill densities that routinely elicit feeding behavior and are visited seasonally; Massachusetts Bay and Cape Cod Bay

Calving—areas routinely used for calving and neonatal nursing; SE United States

Nursery—aggregation area(s) where nursing females feed and suckle; Massachusetts Bay and Cape Cod Bay

Breeding—locations where mating behavior leading to conception occurs; breeding areas are not well known for the North Atlantic right whale.

6. Why does the distribution pattern of right whales change depending on the time of year? Where are the critical areas most often inhabited during the year?

Right whales have occurred historically in all the world's oceans from temperate to subpolar latitudes. They primarily occur in coastal or shelf waters, although movements over deep waters are unknown. For much of the year, their distribution is strongly correlated to the distribution of their prey. During winter, right whales occur in lower latitudes and coastal waters where calving takes place. However, the whereabouts of much of the population during winter remains unknown. Right whales migrate to higher latitudes during spring and summer. The waters of coastal Florida and Georgia, the Great South Channel (east of Cape Cod), and Massachusetts Bay and Cape Cod Bay have been identified as important habitats for right whale foraging, nursing and calving.

Population Trends, Threats, and Conservation

7. Are the western and eastern populations of right whales increasing, decreasing, or leveling off? Explain.



It is believed the western North Atlantic population numbers only 300-400 individual right whales. Recent analysis of sighting data suggests a slight growth in the population size. However, North Atlantic right whales remain critically endangered.

Although precise estimates of abundance are not available for eastern North Atlantic right whales, the population is nearly extinct, probably only numbering in the low tens of animals. It is unclear whether right whales found in the eastern North Atlantic represent a "relict" population or whether all or some of these whales are individuals from the known western North Atlantic population.

LISTEN FOR WHALES

Right Whale Information—Questions: Teacher Version

8. What are the most dangerous threats to right whales?

Ship collisions and entanglement in fishing gear are the most common human causes of serious injury and mortality of western North Atlantic right whales. Additional threats may include habitat degradation, contaminants, climate and ecosystem change, and predators such as large sharks and killer whales.

9. What conservation efforts have been put in place to protect and preserve right whales?

Right whales were first protected by the 1931 Convention for the Regulation of Whaling, which took effect in 1935. In 1949, the International Convention for the Regulation of Whaling protected right whales from commercial whaling.

*In U.S. waters, right whales were determined to be in danger of extinction in all or a significant portion of their range due to commercial over-utilization. As a result, they were listed as endangered under the Endangered Species Conservation Act in June 1970, the precursor to the Endangered Species Act (ESA). The species was subsequently listed as endangered under the ESA in 1973. In the same year, the species was designated as depleted under the Marine Mammal Protection Act (MMPA). In 2008, NMFS listed the endangered northern right whale (*Eubalaena* spp.) as two separate, endangered species: the North Pacific right whale (*E. japonica*) and North Atlantic right whale (*E. glacialis*).*

NOAA Fisheries Service has taken both regulatory and non-regulatory steps to reduce the threat of ship collisions, including: mandatory and voluntary vessel speed, changing of international shipping lanes, aircraft surveys, and right whale alerts.

To address entanglement in fishing gear, NOAA established the Atlantic Large Whale Take Reduction Team. This team developed a plan to reduce the incidental serious injury and mortality of right, humpback, fin, and minke whales in the South Atlantic shark gillnet fishery, the Gulf of Maine and Mid-Atlantic lobster trap/pot fishery, the Mid-Atlantic gillnet fishery, and the Gulf of Maine sink gillnet fishery.

Federal law and Massachusetts state law prohibit coming within 500 yards of a right whale unless permitted by NMFS or unless one of the limited exemptions applies.



LISTEN FOR WHALES

Right Whale Information—Questions: Student Version

North Atlantic Right Whales (*Eubalaena glacialis*)

Introduction and Learning Goals

North Atlantic right whales are one of the most endangered marine species on earth. In this activity you will explore the life history of the North Atlantic right whale, and learn about its distinctive characteristics.



Procedure:

Read the supplemental information sheet and answer the following questions.

Species Description:

1. Describe the distinctive features that separate right whales from other whales.
2. How long do right whales live? How can one determine the age of a right whale?
3. How long is a right whale's gestation period? When and where does calving usually occur?
4. How do right whales feed and what do they typically feed on?

LISTEN FOR WHALES

Right Whale Information—Questions: Student Version

Habitat

5. What are the four major right whale habitats and what distinguishes one from another? Be sure to use the map to specifically locate each major habitat.
6. Why does the distribution pattern of right whales change depending on the time of year? Where are the critical areas most often inhabited during the year?

Population Trends, Threats, and Conservation

7. Are the western and eastern populations of right whales increasing, decreasing, or leveling off? Explain.



8. What are the most dangerous threats to right whales?
9. What conservation efforts have been put in place to protect and preserve right whales?

LISTEN FOR WHALES

Webquest: Teacher Version

North Atlantic Right Whale Sound Detection and Preservation Webquest

listenforwhales.org

Introduction and Learning Goals:

North Atlantic right whales are one of the most endangered species on the planet. Therefore, many measures have been set in place to protect and preserve them. In this webquest you will learn general information about right whales, as well as about how they use sound in their marine environment. You will also explore how scientists can use the whales' sounds to help protect the species.

Procedure:

Go to the home page of the Right Whale Listening Network's website at listenforwhales.org. Follow the procedure below. Be sure to answer all questions thoroughly.

Section I: An Introduction to North Atlantic Right Whales

Click on and view the video "Life as a Right Whale." Then, click on the upper tab "About Right Whales" and select "Quick Facts" to answer the following questions.

1. How many North Atlantic right whales still remain in our oceans? Where are they typically found?

There are an estimated 350-400 whales that still remain in the wild. They reside in and around the East Coast of North America from Newfoundland to Florida.

2. How would you describe the appearance of a North Atlantic right whale?

A North Atlantic right whale is a large, mostly black whale with white patches on the head and belly. They have no dorsal fin and a deeply notched fluke. They have long baleen plates, instead of teeth, that they use to strain their food from the water. They have two blowholes on the top of the head that give a distinctive V-shape to a right whale's spout.

3. Right whales have a potential lifespan of 50 to 70 years. Ship strikes and other threats have reduced life expectancy to 15 years. How does the reduced lifespan affect species survival? (Explain using numbers and potential offspring.)

Female right whales typically breed for the first time at around age nine. The gestation period of a female is around 12 months and every 3-6 years they give birth. If a female were to live 50 years she could give birth to 6-14 calves. Whereas a female with a reduced life span of only 15 years would only be able to give birth to 1-2 calves in her lifetime.



LISTEN FOR WHALES

Webquest: Teacher Version

Section II: Exploring Threats to North Atlantic Right Whales

Return to the home page by clicking on the "Home" link. Then click on the "Threats to Right Whales" tab on the page. View all four links in this section: "Overview," "Ship Strikes," "Entanglement," and "Noise Pollution" to complete the questions below.

4. What are the two main causes of death in right whales? Why does each death have such a huge impact on this small population?

Right whales die from two major causes: ship collisions and entanglement in fishing gear. With fewer than 400 remaining, every death is a severe blow to the species' prospects for survival.

5. Ship strikes are the leading cause of death for right whales. Describe what the National Marine Fisheries Service is doing to protect right whales from ship strikes.

In 1999, in an attempt to reduce ship strikes, the National Marine Fisheries Service (NMFS) began requiring ships to report when they entered either of two "Mandatory Ship Reporting" areas: feeding grounds in Massachusetts waters and calving grounds off Georgia and Florida. When a ship radios in, the NMFS relays locations of recent whale sightings and offers advisories about safe speeds. In 2007, they initiated actions that shifted the shipping channels in Boston Harbor to avoid whale-rich areas.

6. How does noise pollution affect right whales? Explain.

Whales live in a world of sounds, and they use their ears far more than their eyes. Noise pollution doesn't kill them directly, but it makes life difficult. Right whales frequently make calls over distances of 20 miles (32 km) or more. The calls let whales stay in touch, share information about food, help mates find each other, and keep groups together along migration routes. Constant, heavy ship traffic can drown out these sounds, stranding whales in a soup of noise.

Section III: Introduction to Mission: Listen

Return to the "Home" page by clicking on the tab at the top of the page. Once on the home page, scroll down and first view "Swimming in Sounds" and then "Mission: Listen." Once you have viewed both videos click on the tab "Explore Whale Sounds." You will then need to view "How to Read a Spectrogram," "The right whale Up-Call," "Other Whale Sounds," and "Sifting Through Acoustic Smog" to answer the following questions. Be sure to listen to all sound clips on all pages.

7. Explain what a spectrogram is and how to interpret one.

Spectrograms are a visual aid to understanding a sound that you can hear. Frequency (or pitch) is graphed on a vertical axis; time is on the horizontal axis. Darker parts of the graph indicate louder sounds. As a sound plays you can visually follow it across the graph, left to right and see the sound you hear.

LISTEN FOR WHALES

Webquest: Teacher Version

8. What is an up-call and how do right whales use it to communicate?

An up-call is a type of "contact call." The up-call is rather like small talk. Right whales use up-calls to let other whales know they are nearby.

9. Other than the up-call, what other sounds do right whales make? When and why do they make these different sounds?

Right whales make many other calls to send messages to other whales. Right whales make a "moan call" that is an eerie, long, drawn-out call; its purpose is not well understood. The "scream call" is a call that is used when right whales gather in large groups and the "gunshot call" is made by males and is an aggressive sound directed toward other males.

10. What is acoustic smog and what effect does it have on right whales?

Acoustic smog is the constant background noise that is heard in the ocean, largely from human sources such as ships. Acoustic smog reduces right whales' ability to communicate. This could lead to difficulty finding a mate, which eventually could lead to lower reproductive rates.

Section IV: Using Sound as a Solution

Return to the "Home" page by clicking on the tab at the top of the page. Then, click on the "Solutions" tab and select "Avoiding Ship Strikes." In this section you will learn how scientists use sounds that right whales make to help protect them from devastating ship strikes. View all links under this tab starting with number one and ending with number five.

11. Explain, from start to finish, how a right whale call is detected, transmitted, analyzed, and then relayed to ships within shipping lanes.

Auto-detection buoys (underwater hydrophones) first detect the sounds of right whales within 5 nautical miles (9 km). A computer within the auto-detection buoy analyzes the sounds as they arrive. The computer separates the sounds of the whales from the background noise and every 20 minutes relays the 10 highest scoring sound clips to the Cornell Lab of Ornithology. Analysts at the Laboratory sift through the sound clips and make a final determination as to what the sound is and where it has come from. Once a right whale call has been identified, ships that are close or within the shipping lanes in the Massachusetts Bay area are alerted to slow down and watch for whales to avoid a possible ship strike.

12. How might the process described above lead to fewer ship strikes? Explain the idea behind this theory.

The idea behind the process above is to use the sounds of right whales to get an accurate location for the animals so ships in the area can avoid them. Right whales typically feed near the surface and if ships can slow down, the odds of the whale being struck are drastically reduced.

LISTEN FOR WHALES

Webquest: Teacher Version

Section V: Using the Sound Detection Map to Protect Right Whales

Once you have completed section IV, redirect back to the "Home" page by clicking on the tab at the top of the page. Then click on "About Right Whales" and select "Sound Detection Map."

13. Using what you have previously learned in this webquest about right whales and sound, interpret and explain what you see on the sound map and how it is useful in the protection of right whales.

This sound detection map provides the latest detections of endangered North Atlantic right whales in the busy waters of Massachusetts Bay. The map is a live interpretation of where the whales are within the Bay. Knowing where the whales are within the Bay area allows ships to slow in those areas to avoid striking the animals.

LISTEN FOR WHALES

Webquest: Student Version

North Atlantic Right Whale Sound Detection and Preservation Webquest

listenforwhales.org

Introduction and Learning Goals:

North Atlantic right whales are one of the most endangered species on the planet. Therefore, many measures have been set in place to protect and preserve them. In this webquest you will learn general information about right whales, as well as about how they use sound in their marine environment. You will also explore how scientists can use the whales' sounds to help protect the species.

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2. How would you describe the appearance of a North Atlantic right whale?
3. Right whales have a potential lifespan of 50 to 70 years. Ship strikes and other threats have reduced life expectancy to 15 years. How does the reduced lifespan affect species survival? (Explain using numbers and potential offspring.)



LISTEN FOR WHALES

Webquest: Student Version

Section II: Exploring Threats to North Atlantic Right Whales

Return to the home page by clicking on the "Home" link. Then click on the "Threats to Right Whales" tab on the page. View all four links in this section: "Overview," "Ship Strikes," "Entanglement," and "Noise Pollution" to complete the questions below.

4. What are the two main causes of death in right whales? Why does each death have such a huge impact on this small population?
5. Ship strikes are the leading cause of death for right whales. Describe what the National Marine Fisheries Service is doing to protect right whales from ship strikes.
6. How does noise pollution affect right whales? Explain.

LISTEN FOR WHALES

Webquest: Student Version

Section III: Introduction to Mission: Listen

Return to the "Home" page by clicking on the tab at the top of the page. Once on the home page, scroll down and first view "Swimming in Sounds" and then "Mission: Listen." Once you have viewed both videos click on the tab "Explore Whale Sounds." You will then need to view "How to Read a Spectrogram," "The right whale Up-Call," "Other Whale Sounds," and "Sifting Through Acoustic Smog" to answer the following questions. Be sure to listen to all sound clips on all pages.

7. Explain what a spectrogram is and how to interpret one.
8. What is an up-call and how do right whales use it to communicate?
9. Other than the up-call, what other sounds do right whales make? When and why do they make these different sounds?
10. What is acoustic smog and what effect does it have on right whales?

LISTEN FOR WHALES

Webquest: Student Version

Section IV: Using Sound as a Solution

Return to the "Home" page by clicking on the tab at the top of the page. Then, click on the "Solutions" tab and select "Avoiding Ship Strikes." In this section you will learn how scientists use sounds that right whales make to help protect them from devastating ship strikes. View all links under this tab starting with number one and ending with number five.

11. Explain, from start to finish, how a right whale call is detected, transmitted, analyzed, and then relayed to ships within shipping lanes.
12. How might the process described above lead to fewer ship strikes? Explain the idea behind this theory.

Section V: Using the Sound Detection Map to Protect Right Whales

Once you have completed section IV, redirect back to the "Home" page by clicking on the tab at the top of the page. Then click on "About Right Whales" and select "Sound Detection Map."

13. Using what you have previously learned in this webquest about right whales and sound, interpret and explain what you see on the sound map and how it is useful in the protection of right whales.

LISTEN FOR WHALES

Right Whale Data Activity: Teacher Version

North Atlantic Right Whale Data from Massachusetts Bay

Introduction and Learning Goals:

In this activity you will analyze and interpret data collected about right whales in Massachusetts Bay. You will use the data to draw conclusions about the animals' seasonal behavior.

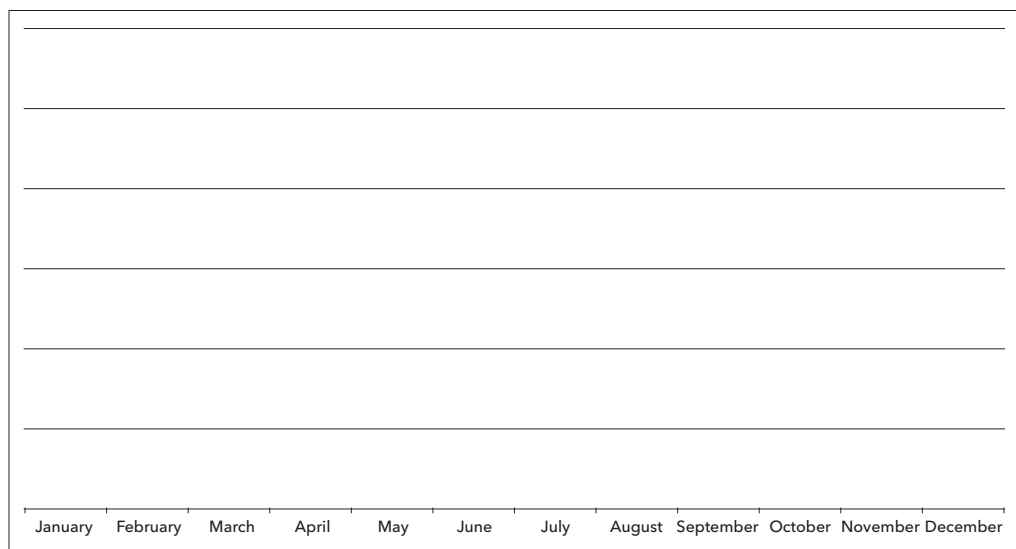
Procedure:

You will begin by making your own predictions about the movement of right whales. Then you will use real data to analyze the migration patterns of right whales and draw conclusions about why they move the way they do. Finally, you will collect your own data over two weeks and draw conclusions about how and why the whales are moving during that period.

Prediction:

1. Use your knowledge of North Atlantic right whale biology to predict when you will hear them in Massachusetts Bay. (Will whales be present throughout the year? Will they be concentrated in one or several seasons?) Draw your predictions using the set of gridlines provided. You may use listenforwhales.org and the Right Whale Information Sheet to help make your prediction.

Number of Right Whale Calls



LISTEN FOR WHALES

Right Whale Data Activity: Teacher Version

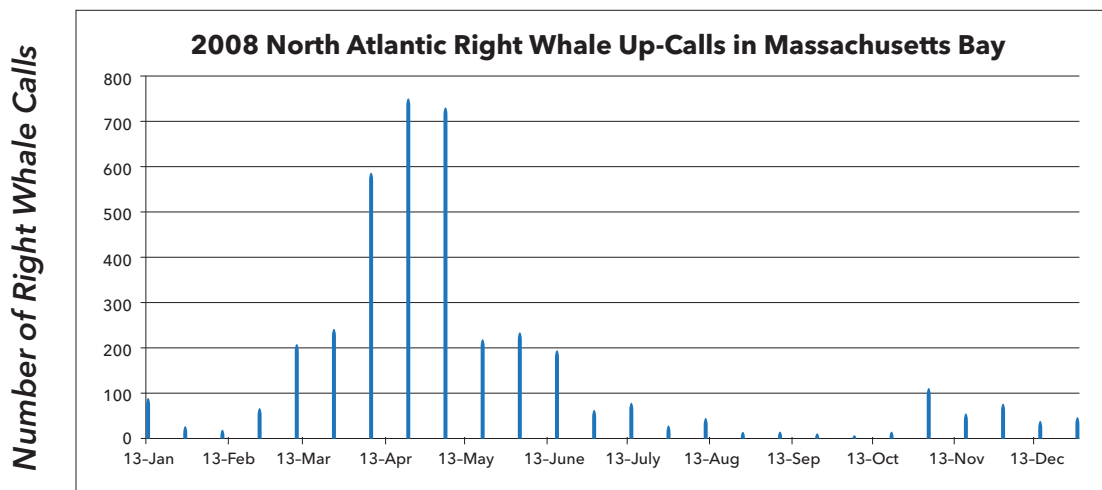
Graph Historical Data

2. Here is a data set showing the number of whale calls detected in Massachusetts Bay in 2008. Graph the data to see when whales were most often present.

North Atlantic right whale calls, Massachusetts Bay, 2008	
Data collected over a 2-week period ending on	Total number whale calls (in 2-week period)
14-Jan	84
28-Jan	23
11-Feb	15
25-Feb	63
11-Mar	205
25-Mar	239
8-Apr	585
22-Apr	748
6-May	728
20-May	214
3-Jun	231
17-Jun	191
1-Jul	57
15-Jul	75
29-Jul	24
12-Aug	40
26-Aug	11
9-Sep	11
23-Sep	7
7-Oct	1
21-Oct	9
4-Nov	107
18-Nov	50
2-Dec	73
16-Dec	34
30-Dec	42

LISTEN FOR WHALES

Right Whale Data Activity: Teacher Version



Data Interpretation

3. When are the whales present in Massachusetts Bay?

Whales are most often heard in April and May.

4. Is this consistent with what you know about the whales' biology? Why or why not?

Yes, the data is consistent. The whales spend their winters along the southeastern Atlantic coast of the United States, where they bear their calves. Massachusetts Bay is known to be a rich feeding ground in the spring. Whale sightings in the spring and early summer are well established.

Interestingly, the data from the buoys has reshaped our understanding of how the whales use Massachusetts Bay. Whales are present throughout the late fall and winter. The data show that right whales use more of the Bay than expected, for more of the year—at this point, no one knows precisely why.

5. Is the data consistent with your prediction? Why or why not?

This answer will vary depending on the student's predictions. The student's explanation should be quantitative, detailed (using the data), and logical.

6. What do the number of calls tell you about the number of whales present in the bay?

The number of calls is a very good way to tell if whales are present or absent in the Bay. However, the buoy data are not good at predicting the NUMBER of whales present.

LISTEN FOR WHALES

Right Whale Data Activity: Teacher Version

Number of Right Whale Calls

Date

Summarization of Collected Data:

7. What can you conclude about the presence of right whales in Massachusetts Bay using your data? Explain.

Answers will vary based on collected data.

No calls might mean that: 1) the animals aren't present, 2) they're present and not calling, or 3) they're present and calling, but outside the area where buoys can detect their sounds.

If calls are detected, the whales are present, though it is difficult to draw any conclusions about the number of whales present.

8. Is the data that you have collected consistent with the data from 2008? Explain.

Answers will vary based on collected data.

Data from these buoys show some variation from year to year. For example, in 2010, large numbers of calls were detected earlier than in 2008. The system detected many more calls on one day (February 25, 2010–124 calls) than for the two-week period ending February 26, 2008 (62 calls).



LISTEN FOR WHALES

Right Whale Data Activity Extension: Teacher Version

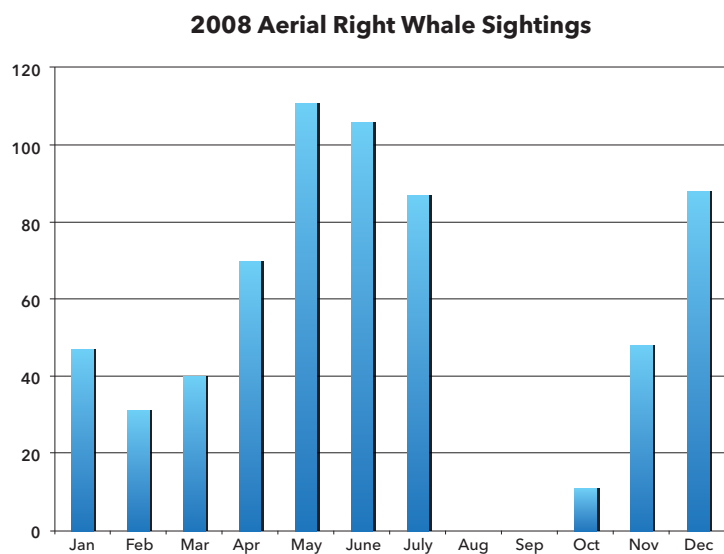
Data Activity

The whale calls detected by The Right Whale Listening Network can show whether or not whales are present in Massachusetts Bay. However, whale call data are not good at predicting the number of whales present. Though recent research shows a strong positive relationship between the number of calls and the number of whales present, it's hard to tell how many whales are present. A few whales can make many calls—skewing the data.

Currently, the best way to predict the number of whales present in the Bay is to use aerial surveys. The National Oceanic and Atmospheric Administration (NOAA) undertakes these surveys every year. The data below is an excerpt from the 2008 survey. The aerial survey is available at <http://goo.gl/pdfQR>.

Note that most sightings occur in May and June (a bit later than the peak of call detection.) You could have your students make this comparison as an extension exercise. You may also want to note to students that the number of whales sighted will depend on the number of hours of flight time.

NOAA aerial sightings of right whales, 2008		
Month	Number aerial sightings	Flight hours
Jan	47	30
Feb	31	29
March	40	23
April	70	50
May	111	18
June	106	32
July	87	38
August	0	0
Sept	0	0
Oct	11	27
Nov	48	29
Dec	88	19



LISTEN FOR WHALES

Right Whale Data Activity: Student Version

North Atlantic Right Whale Data from Massachusetts Bay

Introduction and Learning Goals:

In this activity you will analyze and interpret data collected about right whales in Massachusetts Bay. You will use the data to draw conclusions about the animals' seasonal behavior.

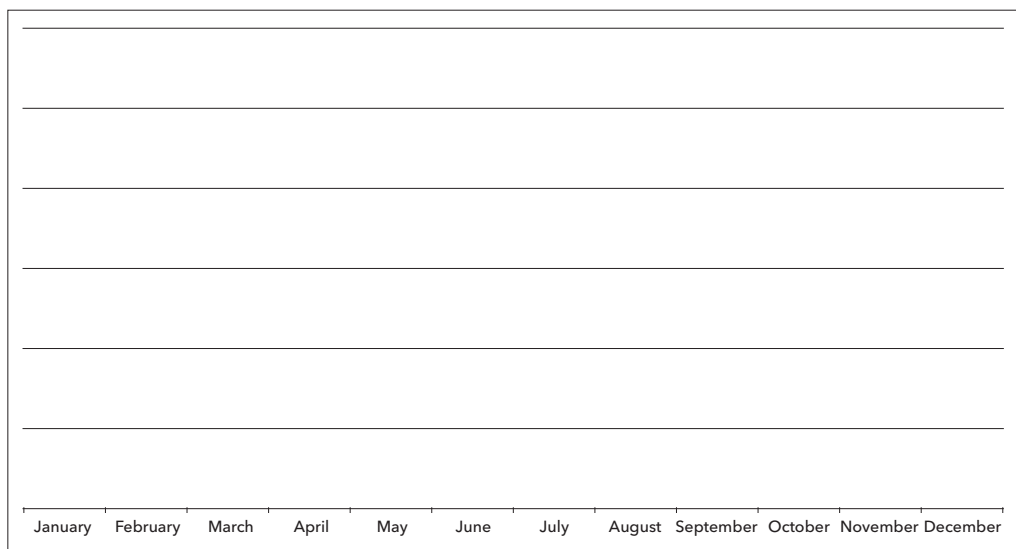
Procedure:

You will begin by making your own predictions about the movement of right whales. Then you will use real data to analyze the migration patterns of right whales and draw conclusions about why they move the way they do. Finally, you will collect your own data over two weeks and draw conclusions about how and why the whales are moving during that period.

Prediction:

1. Use your knowledge of North Atlantic right whale biology to predict when you will hear them in Massachusetts Bay. (Will whales be present throughout the year? Will they be concentrated in one or several seasons?) Draw your predictions using the set of gridlines provided. You may use listenforwhales.org and the Right Whale Information Sheet to help make your prediction.

Number of Right Whale Calls



LISTEN FOR WHALES

Right Whale Data Activity: Student Version

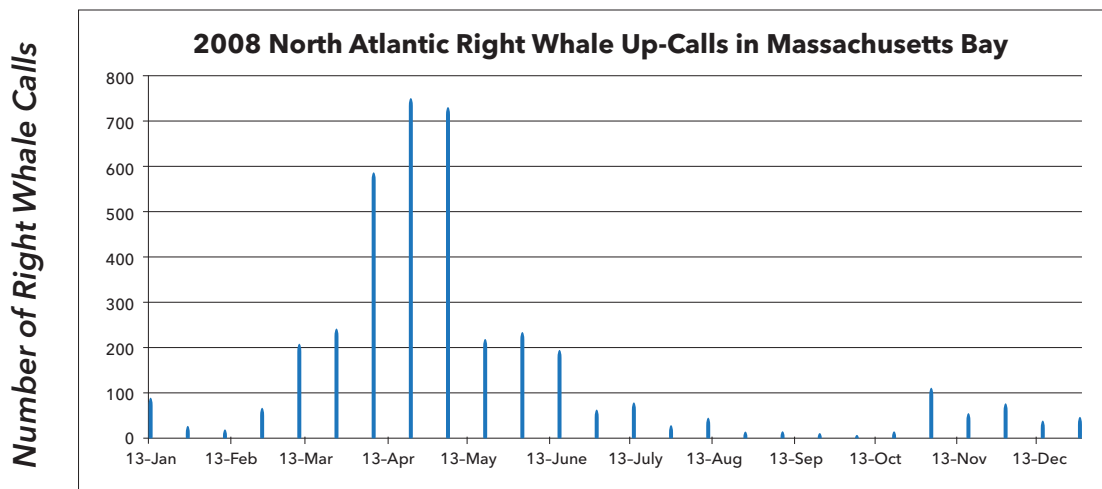
Graph Historical Data

2. Here is a data set showing the number of whale calls detected in Massachusetts Bay in 2008. Graph the data to see when whales were most often present.

North Atlantic right whale calls, Massachusetts Bay, 2008	
Data collected over a 2-week period ending on	Total number whale calls (in 2-week period)
14-Jan	84
28-Jan	23
11-Feb	15
25-Feb	63
11-Mar	205
25-Mar	239
8-Apr	585
22-Apr	748
6-May	728
20-May	214
3-Jun	231
17-Jun	191
1-Jul	57
15-Jul	75
29-Jul	24
12-Aug	40
26-Aug	11
9-Sep	11
23-Sep	7
7-Oct	1
21-Oct	9
4-Nov	107
18-Nov	50
2-Dec	73
16-Dec	34
30-Dec	42

LISTEN FOR WHALES

Right Whale Data Activity: Student Version



Data Interpretation

3. When are the whales present in Massachusetts Bay?
4. Is this consistent with what you know about the whales' biology? Why or why not?
5. Is the data consistent with your prediction? Why or why not?
6. What do the number of calls tell you about the number of whales present in the bay?

LISTEN FOR WHALES

Right Whale Data Activity: Student Version

Number of Right Whale Calls

Date

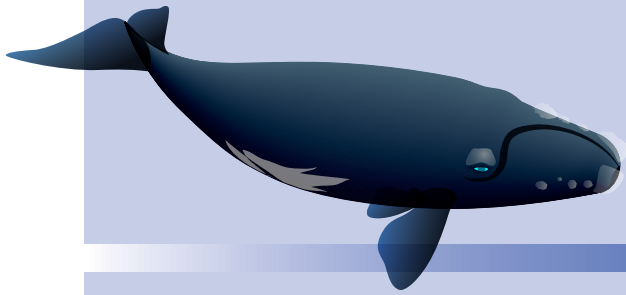
Summarization of Collected Data:

7. What can you conclude about the presence of right whales in Massachusetts Bay using your data? Explain.

8. Is the data that you have collected consistent with the data from 2008? Explain.



SEA OF SOUND



SOUND MASKING

Teacher Notes

Before You Start

Time Frame

- Watch *Sea of Sound* DVD (30 minutes). Emphasize “Anthropogenic Sounds” chapter and particularly the section “Changing the Ocean Soundscape.”
- **Introductory Activity:** 15 minutes.
- **Sound Masking Webquest:** 30 minutes.
- **Masking Video Data Activity:** 30 minutes
- Watch Interview DVD (20 min). See teaching tips below for sections to emphasize.
- Teacher prep time: less than 1 hour for the entire unit.

Grade Level: 10–11

Appropriate for grades 6–12, with extension activities.

Materials Needed

- Computers with web browsing capability and ability to play .mov or .mp4 format video
- Sound source for intro activity—e.g. CD player with music or taped conversation
- “Masking sound data” video. Found in the Resources section of the DVD, or on seaofsound.org.
- **Masking Video Data Activity**
- **Sound Masking Webquest**

Getting Ready

- Watch *Sea of Sound* video.
- Choose which activities to use: **Introductory Activity**, **Sound Masking Webquest**, and/or **Masking Video Data Activity**
- Reproduce student handouts

Overview

Sound masking—where one sound obscures another—is a serious problem for marine mammals. Human-created sounds such as boat noise, Navy sonar, and oil exploration all interfere with organisms’ ability to communicate with one another.

Learning Objectives

Students will be able to:

- describe sound masking;
- describe sources of sound that mask and animal sounds that are masked;
- analyze and interpret a video showing data from underwater microphones;
- identify and analyze the effects of boat traffic on marine animals.

Activity Overview

Students:

- watch *Sea of Sound* video;
- do **Introductory Activity** to experience sound masking;
- do **Sound Masking Webquest** to learn about the basics of sound masking;
- do **Masking Video Data Activity** to analyze real sound masking data from Massachusetts Bay.

Prior knowledge

Before beginning this set of activities, students should have familiarity with the following:

- **Marine** animals use sound for communication, defense, and reproduction.
- **Endangered species:** a group of organisms at risk of extinction because the population is so small.
- **Hydrophone:** an underwater microphone.
- **Decibel (dB):** the unit used to measure the intensity of sounds. Decibels are calculated as a logarithmic ratio between two values. Therefore the measurement is dependent on a reference value, which should be explicitly given whenever dB is used. The standard pressure in air is usually 20 micro pascals, and the standard for measurement in water is usually 1 micro pascal. Therefore the dB in water and dB in air are not directly comparable. For a more thorough explanation see the DOSITS website.

<http://goo.gl/hSKKS>

Teaching Tips

These activities are modular, so you can mix-and-match to create a combination that fits your classroom.

You may wish to use the *Sea of Sound* video as an introduction to the unit. Note that the DVD contains a **Viewing Guide**, **Teacher Notes**, and a **Matrix** aligning the video content with national middle and high school standards.

Introductory Activity

- The purpose of the activity is to have students experience sound masking. Students will read out loud to one another while you gradually increase the level of background noise. It is best if they do not know your intent ahead of time.

Masking Webquest

- Consider giving students an overview of the activity before starting the webquest. Showing students how to navigate through the websites will make it run smoothly.
- The webquest uses two websites. Please check that links are working before starting the activity.

Masking Data Video

- Make sure each student has the “Masking sound data” video. It is in the Resources section of the DVD, or on seaofsound.org. Also, be sure that the videos can open on all computers used by students.
- The video is silent. You may want to show students the video once and explain what they see before they begin the activity.
- Be sure that students understand the axes and title of the graph in the video. Point out the loudness scale on the right, the time counter at the top, and latitude and longitude on the x- and y-axes.
- The video shows real sound data of whales and boats recorded on underwater microphones in Massachusetts Bay. It translates sound data into colors to indicate sources of sound in the Bay. The small turquoise ovals are endangered North Atlantic right whales vocalizing. The larger yellow ball of light that crosses the screen is sound generated by a ship.

Interview with Dr. Christopher Clark

- The DVD contains a 20 min interview. (See page 16 for details.) You can access each question directly from the “Interview” menu on the DVD. For this activity, play or emphasize his answers to the following questions:
 - What ocean animals use sound?
 - How do animals make and hear sound underwater?
 - What man-made sound is the noisiest?
 - What effect does noise have on animals?

Extensions

- The DVD contains resources for exploring The Right Whale Listening Network—the source of the masking activity data. The Sound and the Protection of Right Whales Activities include 1) **Listen For Whales Webquest** guide to the listenforwhales.org website, and 2) a **Right Whale Data Activity** graphing annual data from underwater microphones and using it to understand whale behavior.
- The DVD also contains resources for holding an in-class **Congressional Hearing** about whether or not to fund The Right Whale Listening Network, from which data for masking activities is derived.
- **Math and Geography Extension:** have students calculate the number of kilometers in a degree of longitude. The number of kilometers in a degree of longitude will vary, given the latitude.
 - At the equator, there are 111.325 km in a degree of longitude. (At the equator, the earth’s circumference is 40,076 km. Divide that by 360 degrees in a circle to get 111.32km/degree.)
 - At the poles, the distance is zero because all the lines come together. The formula is distance = cos (latitude) x 111.325km.
 - At 42.4 degrees longitude, one degree is $.73826 \times 111.325 = 82.2\text{km}$.



Resources

- This activity utilizes resources available at listenforwhales.org.
- Data from auto-detection buoys like those used in this exercise were used to shift the shipping lanes in Boston's harbor to protect the right whale. (<http://goo.gl/8hwC9>)
- A gallery of whale sounds (and other marine mammals) is available from the University of Rhode Island. (dosits.org/audio/marinemammals/)
- The DOSITS website has classroom-ready hands-on activities such as how to build an inexpensive hydrophone and an activity using sound to track whales in the oceans. (dosits.org/resources)
- The DOSITS site also has tutorials and resources for understanding sound in the oceans, how animals use sound, and the physics of sound. (dosits.org/tutorials/scit-intro.htm)

National Science Education Standards

UNIFYING CONCEPTS AND PROCESSES: Systems, Order and Organization; Evidence, Models, and Explanation; Change, Constancy, and Measurement; Evolution and Equilibrium

SCIENCE AS INQUIRY: Abilities Necessary to Do Scientific Inquiry; Understanding About Scientific Inquiry

LIFE SCIENCE: Interdependence of Organisms; Behavior of Organisms

SCIENCE AND TECHNOLOGY: Understanding About Science & Technology

PERSONAL AND SOCIAL PERSPECTIVES: Population Growth; Environmental Quality; Natural and Human induced hazards.

Ocean Literacy Principles

For detailed descriptions, see pages 3–4 of this guide or the framework diagram at oceanliteracy.wp2.coexploration.org.

The ocean supports a great diversity of life and ecosystems (5).

- Grades 6–8— B9
- Grades 9–12—C27

The ocean and humans are inextricably interconnected (6).

- Grades 6–8—D18, E1, and E6
- Grades 9–12—D11, D12, and E6

Standards-alignment matrices are available on the DVD or at seaofsound.org.

Acknowledgments

By Elizabeth Rice, Ph.D., Creative Curriculum, for *Sea of Sound*. Art by Daniel Deibler. Edited by Marc Dantzker. Designed by Joanne Avila. If reproducing this version, please cite *Sea of Sound* as the source and provide the following URL: seaofsound.org.

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SOUND MASKING

Introductory Activity

The purpose of the activity is to have students experience sound masking. As background noise increases, they will talk louder, draw closer together, or stop talking altogether. These are all actions that marine mammals take in response to sound masking.

You will ask students to read aloud in pairs. As students read, you will increase the background level of noise by gradually turning up the volume on a recording. You can use a CD, DVD, or your computer to do this.

Materials:

- Student reading material: possibly a relevant selection from the DOSITS web site <http://goo.gl/WQgYK>, but anything is suitable.
- A sound player: CD player, DVD player, or computer
- A sound recording: NPR story (suggestions below), CD, or DVD such as *Sea of Sound*.

Teaching Tips:

- Test the sound player ahead of time to make sure it will reach a volume high enough to interfere with students' ability to hear while reading aloud.
- It is best if students do not know your intent as you increase the level of background noise.
- The students may read anything they wish. The suggested reading on sources of sound is relevant to the subject of sound masking, but not essential for this activity. Students do NOT need to finish it.
- Increase sound levels very gradually so students will "adapt" to changing circumstances without realizing what is happening.
- Suggested NPR stories for background sound (each is about 3 minutes long):
 - Oceans are becoming noisier: <http://goo.gl/sxqUU>
 - Undersea microphones and hurricane detection: <http://goo.gl/Gyklz>
 - Volcano and whale sounds: <http://goo.gl/wUuN0>
- After the background noise is sufficiently loud, call out, "FREEZE!" Have students evaluate their body positions and behaviors relative to how they began the reading exercise.



SOUND MASKING

Webquest: Teacher Version

Introduction and Learning Goals:

In this webquest, you will use internet resources to learn about sound masking. You will learn what sound masking is, the sources of sound masking, and how masking affects marine mammals.

Section I: What is "Sound Masking?"

Go to the Masking page of the University of Rhode Island's DOSITS website at <http://dosits.org/animals/effectsofsound/marinemammals/masking/> or <http://goo.gl/5PRZV>. Follow the procedure below. Be sure to answer all questions thoroughly.

1. What is sound masking? What causes it? What effects does it have?

When one sound (usually louder or at the same frequency) "drowns out" another sound, the sound has been masked.

Natural sources: e.g. snapping shrimp, wind, waves, rain, animals.

Human-derived sources: e.g. boat motors, propeller bubbles, Navy sonar, underwater geological exploration, shipping traffic, tankers, fishing boats, etc.

Masking "hides" animals' sounds. This is of particular importance when mating calls, and warnings of danger can not be heard.

2. How do marine mammals change their behavior in reaction to masking? Give an example from a research study.

Animals may change their behavior or move away. They could make louder calls, more calls, or change the frequency of their calls.

Study 1: Killer whales. The study compared killer whale calls with and without boat noise from 1977 and 2003. In 2003, the killer whales used longer calls, suggesting that the increased boat traffic between 1977 and 2003 caused changes in their behavior.

Study 2: Beluga whales. Belugas reduced their calling as a ferry and a motorboat approached. Then, when the boats were within one kilometer, they increased a certain call. They also shifted frequencies and calls.

Study 3: Beluga whales. Belugas called more loudly in a louder environment. This is called the Lombard Vocal Response. Increasing loudness is a coping mechanism for life a noisy environment, but it has energy costs for the animals involved and will not work beyond a certain, unknown threshold.

Section II: What Does "Masking" Sound Like?

Go to the website listenforwhales.org/Page.aspx?pid=432. This is the website for the Right Whale Listening Network in Massachusetts Bay. The network uses underwater microphones in Massachusetts Bay to record the sounds of the critically endangered North Atlantic right whale. There are only 300-400 of these whales left on the planet.

SOUND MASKING

Webquest: Teacher Version

3. What does a right whale “up-call” sound like? Why does the project listen for the “up-call?”

In this recording the up-call is easy to hear—a deep, rising “whoop” that lasts about a second.

The up-call is useful because it’s distinctive and right whales produce it often. A type of “contact call,” the up-call is rather like small talk—the sound of a right whale going about its day and letting others know it’s nearby.

4. Can you hear the up-call with environmental noise?

Probably not. The shipping noise almost completely masks the whale’s call. The Right Whale Listening Network uses software that can distinguish whale sounds from background noise.

5. Do you think a whale could hear the “up-call” with environmental noise? Why or why not?

It would depend on how far the listening whale was from the calling one. If the two animals were close together (think about two people trying to converse in a noisy room) they could probably hear one another. If the two animals were farther apart, they could not.

Section III: Listen to Sounds that Mask

Go to the website: listenforwhales.org/Page.aspx?pid=443. This page gives examples of human-made sounds that mask animal sounds.

6. Describe three sounds that can mask animals’ sounds.

Boats, Navy sonar, oil exploration.

The audio track plays the sound of a tanker passing by an underwater microphone. The video shows sound produced by a motorboat, Navy sonar, oil exploration, and a tanker. The human-made sounds drown-out those of humpback whales and orcas.

7. How long does boat noise persist?

A ship traveling at 10 knots takes an hour to traverse an auto-detection buoy’s 10-nautical-mile-wide listening area.

8. What is “acoustic smog” and what effect does it have on right whales? Explain.

Acoustic smog is the constant background noise that is heard in the ocean, largely from human sources such as ships. Acoustic smog reduces right whales’ ability to communicate. This could lead to difficulty finding a mate, which eventually could lead to lower reproductive rates—a critical problem for a severely endangered species.

SOUND MASKING

Webquest: Student Version

There are only 300-400 of these whales left on the planet.

3. What does a right whale "up-call" sound like? Why does the project listen for the "up-call?"
4. Can you hear the up-call with environmental noise?
5. Do you think a whale could hear the "up-call" with environmental noise? Why or why not?

Section III: Listen to Sounds that Mask

Go to the website: listenforwhales.org/Page.aspx?pid=443. This page gives examples of human-made sounds that mask animal sounds.

6. Describe three sounds that can mask animals' sounds.
7. How long does boat noise persist?
8. What is "acoustic smog" and what effect does it have on right whales? Explain.

SOUND MASKING

Masking Video Data Activity: Teacher Version

Introduction and Learning Goals:

In this activity you will work with real data from Massachusetts Bay to explore the effects of boat sound on the endangered North Atlantic right whale. The data is collected by an array of underwater microphones, called hydrophones, situated around the Bay. You will see the effects of a passing ship on whales calling in the Bay.



North Atlantic right whales are one of the most endangered species on the planet. Only 300-400 remain in the world. Massachusetts Bay is an important spring feeding ground for them. From March to May, large numbers of whales are often present.

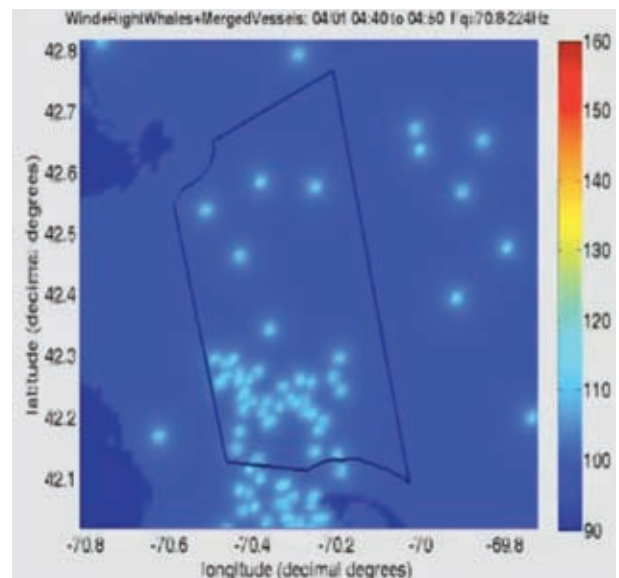
Procedure:

Open the video called **Masking Sound Data**. Watch the 20-second video all the way through. Then return to the beginning of the video and begin to answer the questions below.

What do I see?

The video shows sound as light. The louder the sound is, the brighter the color shown. The loudness scale—measured in underwater decibels and shown on the right side of the image—runs from quiet blues to loud reds. Each frame of the video is a 10-minute snapshot of sound in the Massachusetts Bay, as picked up by underwater microphones. This 20-second clip shows 12 hours of data. Time is shown at the top of the image.

The line in the ocean is the outline of Stellwagen Bank National Marine Sanctuary. <http://stellwagen.noaa.gov/>. The sanctuary is a place where endangered North Atlantic right whales are known to congregate.



Part I: Whales and Background Noise

The calling whales are the light blue dots. Approximately how many whales do you see?

There are between 55 and 65 whales in the video's opening frame.

What is the dark blue around the left-hand edge of the frame?

Land. You can see the "hook" of Cape Cod at the bottom of the image.

SOUND MASKING

Masking Video Data Activity: Teacher Version

When was this data taken?

April 1, 2008. Data starts at 4:10AM and goes until 4:10PM

What is the baseline sound level in Massachusetts Bay?

Around 95 dB.

How loud is this? What causes the baseline sounds in the Bay?

95dB is relatively quiet. It is quieter than most well-characterized marine animal sounds. Baseline sounds are caused by wind, waves, bubbles, and other natural phenomena.

How loud are the whale's calls? What's the maximum value?

Around 115 dB. Students can calculate any distance in the activity using EITHER latitude or longitude. We provide both calculations. Calculations will vary depending on the initial "size" estimate, of the sound, which is somewhat approximate and will vary depending on which sound the student chooses to estimate.

How far do the calls reach?

~0.04 degrees longitude. $0.04 \text{ degrees long} \times 82 \text{ km/degree} = 3.2\text{km}$

~0.03 degrees latitude. $\times 111 \text{ km} = 3.3\text{km}$

Part II: Boat Traffic

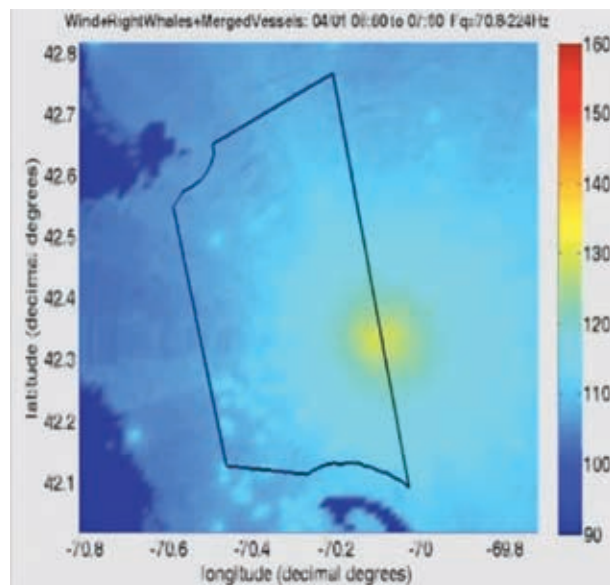
The shipping lanes into Boston Harbor pass through the habitat of the endangered right whale. What happens to whales when a ship passes through?

The yellow ball of light that crosses the screen is a boat. How long does it take a boat to cross from the open ocean (right side of the screen) through the shipping channels into Boston (to the left of the screen).

About 5 hours. For example, from 4:10 to 9:10.

How loud is the boat? Maximum value?

The loudest part of the sound is represented by the yellow core of the boat circle. The innermost circle is around 130 dB.



SOUND MASKING

Masking Video Data Activity: Teacher Version

How wide is the loudest part of its sound, in kilometers? How big is this (explain in your own words)?

The loudest part of the sound is represented by the yellow core of the boat circle. The innermost circle is about 0.1 degree longitude. $0.1 \text{ degrees long} \times 82 \text{ km/degree} = 8 \text{ km}$

$\sim 0.08 \text{ degrees latitude. } \times 111 \text{ km} = 8.8 \text{ km}$

8 kilometers is 5 miles—it would take about an hour to walk that far (depending on how fast one walks). It could be the distance between home and school. Between downtown and the grocery store.

How wide is the boat's sound "halo" in kilometers? How big is this?

At least one full degree longitude. $1 \text{ degree longitude} \times 82 \text{ km/degree} = 82 \text{ km}$

About 0.8 degrees latitude. $0.8 \text{ degrees latitude} \times 111 \text{ km} = 88 \text{ km}$

84 km is about 53 miles. This could be the distance between two cities. It would take you an hour to drive on a country highway with no traffic.

When the boat is in the middle of the frame, how loud is the boat's echo at the edges of the frame?

Around 115 dB.

Can you see the whales when there is a boat in the middle of the frame?

Not really. Maybe hints around the edges.

What does this mean for the whales? (Hint: what you're seeing is what the whales are hearing)

If you can't see a dot representing a whale, the animal can't be heard above the boat noise. This is sound masking. The sounds of the boat cover up the whales' sounds, and the whales cannot hear one another.

Pick a whale in the middle of the screen to watch while one (and only one) boat goes by. How long does the whale "disappear" while the boat passes through? What does this mean?

A whale "disappears"—meaning it is drowned out by boat noise—for at least two hours.

What is sound masking? Use data from the video clip to explain sound masking.

Sound masking is when one noise masks or "hides" another. In this case, a passing boat is so loud, and its sound is so long-lived, that it can drown out the sounds of whales for two hours. The noise "halo" of the passing boats in this video (not to mention the actual boats!) is louder than the whale calls. Therefore they cannot hear one another when a boat is nearby.

What effects can sound masking have on an endangered species like the North Atlantic right whale?

Sound masking can obscure the mating calls from the right whale. This reduces the whales' ability to find each other and mate, thus reducing reproductive opportunities. Limiting reproductive opportunities, in any way, of a severely endangered species can have serious long-term consequences for the survival of the species.

SOUND MASKING

Masking Video Data Activity: Student Version

Introduction and Learning Goals:

In this activity you will work with real data from Massachusetts Bay to explore the effects of boat sound on the endangered North Atlantic right whale. The data is collected by an array of underwater microphones, called hydrophones, situated around the Bay. You will see the effects of a passing ship on whales calling in the Bay.



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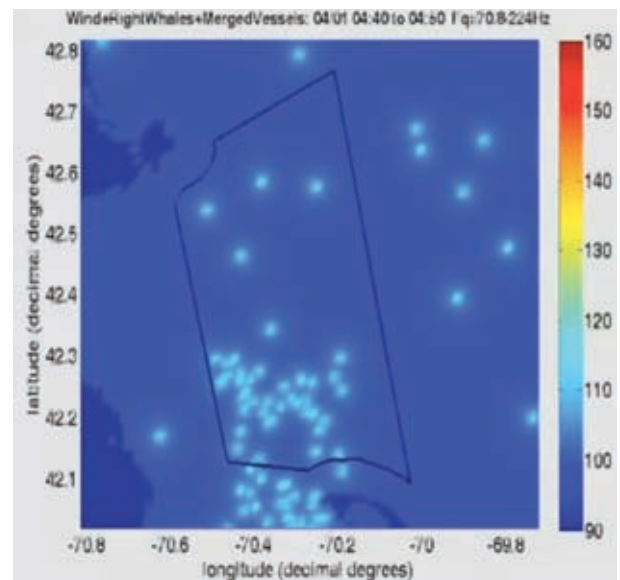
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What do I see?

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Part I: Whales and Background Noise

The calling whales are the light blue dots. Approximately how many whales do you see?

What is the dark blue around the left-hand edge of the frame?

SOUND MASKING

Masking Video Data Activity: Student Version

When was this data taken?

What is the baseline sound level in Massachusetts Bay?

How loud is this? What causes the baseline sounds in the Bay?

How loud are the whale's calls? What's the maximum value?

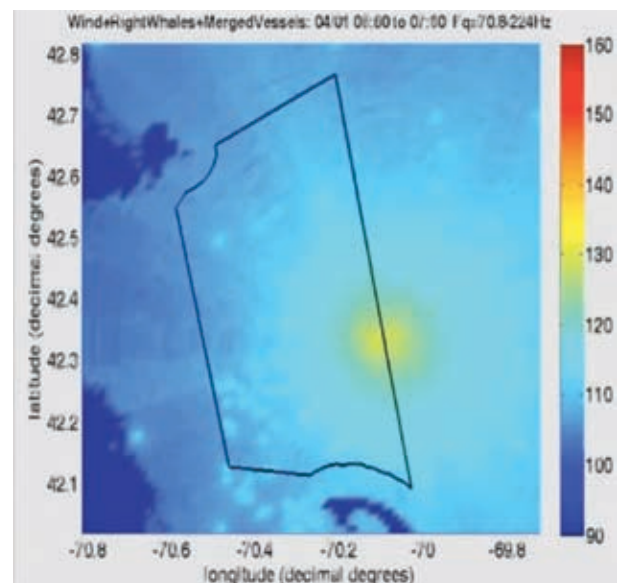
How far do the calls reach?

Part II: Boat Traffic

The shipping lanes into Boston Harbor pass through the habitat of the endangered right whale. What happens to whales when a ship passes through?

The yellow ball of light that crosses the screen is a boat. How long does it take a boat to cross from the open ocean (right side of the screen) through the shipping channels into Boston (to the left of the screen).

How loud is the boat? Maximum value?



SOUND MASKING

Masking Video Data Activity: Student Version

How wide is the loudest part of its sound, in kilometers? How big is this (explain in your own words)?

How wide is the boat's sound "halo" in kilometers? How big is this?

When the boat is in the middle of the frame, how loud is the boat's echo at the edges of the frame?

Can you see the whales when there is a boat in the middle of the frame?

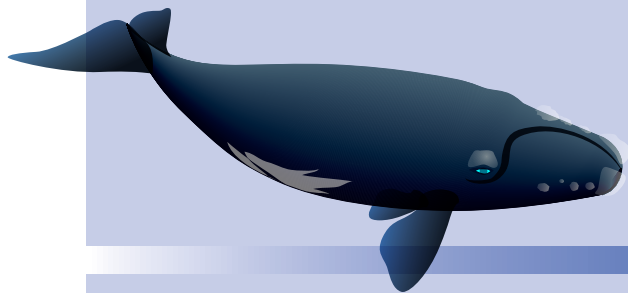
What does this mean for the whales? (Hint: what you're seeing is what the whales are hearing)

Pick a whale in the middle of the screen to watch while one (and only one) boat goes by. How long does the whale "disappear" while the boat passes through? What does this mean?

What is sound masking? Use data from the video clip to explain sound masking.

What effects can sound masking have on an endangered species like the North Atlantic right whale?

SEA OF SOUND



BIODIVERSITY OF MARINE SOUND

Teacher Notes

Before You Start

Time Frame

- Watch *Sea of Sound* DVD (30 min). Emphasize Chapters 1 and 2 on natural and animal sounds (total duration 15:30 min).
- **Natural History and Anatomy:** 45 min.
- **Analyzing Animal Sound:** 45 min.
- Teacher prep time: 1 hour for entire unit.

Grade Level: 10

Appropriate for grades 6-12

Materials Needed

- *Sea of Sound* DVD
- DVD player and display (TV)
- General handouts: **Notetaking Chart**, and **Summary Questions**

Natural History and Anatomy

- Handouts: **Natural History and Anatomy**, and **Natural History and Anatomy Questions**.

Analyzing Animal Sound

- For sound comparisons, student computers with **Raven Lite** installed (program on DVD)
- Find all sounds for this exercise in the **Raven Lite** "File" menu under either "Open Sound" or the "Sea of Sound Playlist."
- Handouts: **Analyzing Animal Sound**, **Analyzing Animal Sound Question Sheet**, and **Raven Lite Guide**

Getting Ready

- Watch *Sea of Sound* video.
- Choose which activities to use: **Natural History and Anatomy** and/or **Analyzing Animal Sound**.
- Reproduce student handouts.
- Make sure **Raven Lite** opens, plays and records sounds on all computers.

Overview

Students will examine how and why different marine organisms use sound, with an emphasis on anatomy, behavior, evolutionary adaptations, and constraints. Students will manipulate and analyze sound using a version of the same software that many acoustics researchers use.

Learning Objectives

Students will know:

- how sound can be described and characterized both qualitatively and quantitatively;
- a variety of sound generating anatomical structures in ocean animals;
- how sound can be visualized and analyzed using software.

Students will understand that:

- there are many types of sounds made by animals in the ocean and that the characteristics of those sounds vary;
- different anatomical structures may produce different sounds;
- many ocean animals have evolved to use sound as a means of communication;
- mammals in the ocean have evolved over time so that their respiratory and sound-producing anatomical structures have particular adaptations for life in the water.

Students will be able to:

- compare and contrast the anatomical structures used by different ocean organisms to produce sound;
- qualitatively and quantitatively compare and contrast the sounds produced by different animals;

Investigation Overview

This lesson is modular. The activities can be done independently or used together.

- **Natural History and Anatomy:** Explore how and why five animals use sound.
- **Analyzing Animal Sound:** Manipulate and visualize animal sound with the Raven Lite program.

Prior knowledge

Before beginning this set of activities, students should have familiarity with the following:

- **Sound** is a mechanical wave.
- **Amplitude** is the height of a wave from the midpoint.
- **Frequency** is the number of waves that pass a point in one second. It is measured in **Hertz** (Hz) or cycles per second.
- **Sound** travels faster in water than in air.
- **Marine mammals** can be divided into major groups, three of which are **pinnipeds** (seals, sea lions, walrus), **mysticetes** (baleen whales), and **odontocetes** (toothed whales like dolphins, narwhal, beluga and killer whales).
- **Hydrophone:** an underwater microphone.
- **Decibel (dB):** the unit used to measure the intensity of sounds. Decibels are calculated as a logarithmic ratio between two values. Therefore the measurement is dependent on a reference value, which should be explicitly given whenever dB is used. The standard pressure in air is usually 20 micro pascals, and the standard for measurement in water is usually 1 micro pascal. Therefore the dB in water and dB in air are not directly comparable. For a more thorough explanation see the DOSITS website. <http://goo.gl/hSKKS>

Teaching Tips

These activities are modular, so you can mix-and-match to create a combination that fits your classroom.

- Watch the “Animal Sounds” chapter of the *Sea of Sound* video. Direct students to pay attention to what sounds animals make, how they make the sounds, and why they make the sounds. Have students take notes in the **Notetaking Chart**.
- Also note that the DVD contains a **Viewing Guide, Teacher Notes**, and a **Matrix** aligning the video content with national middle and high school standards.
- Although this is a very student-centered activity, the teacher will need to actively monitor students’ progress and understanding of each activity.

Natural History and Anatomy

- Divide students into five groups. Each group becomes “expert” on one animal group (invertebrates, fish, pinnipeds, baleen whales, or toothed whales).
- In those same groups, students review what they have learned and prepare to teach others in the class about sounds in their animal group.
- Students reorganize into mixed animal groups; each group has five students, one from each of the animal groups. Each student teaches the others how his/her animal group produces sound, why the animals produce sound, and the diversity and characteristics of the sounds.
- Alternately, you may wish to have each original animal group prepare a short presentation and teach the whole class at once.
- Encourage students to take notes.



- Students should record their answers on the *Natural History and Anatomy Question Sheet*.
- If you have installed **Raven Lite**, your students can access and play each animal's sounds from the "File" menu/"Sea of Sound Playlist."

Analyzing Animal Sound

- All students do the same activity, exploring marine animal (and their own) sounds with the **Raven Lite** computer program (available on the DVD or download from seaofsound.org). The sounds are accessible from the "Sea of Sound Playlist" or using "Open Sound File" in the "Biodiversity" folder.
- Note that **Raven Lite** is designed for visualizing sound, not sound analysis. We ask students to take quantitative measurements, though the software is not optimized for that. Researchers and professionals use the full version of Raven for taking measurements.
- Students should record their answers on the *Analyzing Animal Sound Question Sheet*.

Extensions

- The DVD also contains activities developed for high school physics—**Seeing Sound, Speed of Sound**, and **Extreme Animal Communication**—investigating the properties of sound waves using Raven Lite.
- Anatomy extension: students explore the anatomical differences within the pinnipeds or compare marine mammal structures to those of land mammals. A good source is Tyack, P., and E.H. Miller (2002). Vocal anatomy, acoustic communication, and echolocation. pp 142–184 in *Marine Mammal Biology: An Evolutionary Approach* (A.R. Hoelzel, ed.). Blackwell Science, Oxford, England. It is available from Ted Miller's website at https://www.mun.ca/biology/tmiller/pdffiles/TYACK_2299.pdf.

Resources

- The *Sea of Sound* DVD contains a video interview with Senior Scientific Advisor, Dr. Christopher Clark. The first six sections are relevant to this activity. [-11 minutes].
 - What ocean animals use sound? [1:12]
 - How do animals make and hear sound underwater? [1:22]
 - How do you discover which animals are making which sound? [1:39]
 - Why do so many animals use sound? [1:44]
 - How do large whales make long-distance calls? [1:13]
 - Do some marine mammals "see" with sound? [3:18]
- Information about specific marine mammals is available from the NOAA Fisheries Office of Protected Species at www.nmfs.noaa.gov/pr/species/.
- Information about the evolution of whales is available at <http://goo.gl/HrUyQ>.
- A classroom-ready math and science lesson, the Impact of Sound on the Harbor Porpoise, is available at <http://goo.gl/pLS2O>.
- Sounds of the critically endangered North Atlantic right whale are being used for its own protection, as introduced in the last chapter of the *Sea of Sound* video. Find additional information at listenforwhales.org. The DVD also contains a webquest exploring this site and several exercises using the whale sound data.

- Additional sounds are available from the Macaulay Library marine collection at <http://goo.gl/myl5J>. Files are in a format you can play or open in Raven Lite. Right-click on the file to download.
- A gallery of animal sounds is also available from the University of Rhode Island at dosits.org. The DOSITS website has classroom-ready hands-on activities such as how marine animals use non-vocal sounds, simulated humpback communication, and dolphin echolocation. Additionally, the site has tutorials and resources for understanding sound in the oceans, how animals use sound, and the physics of sound.

National Science Education Standards

UNIFYING CONCEPTS AND PROCESSES: Systems, Order and Organization; Evidence, Models, and Explanation; Change, Constancy, and Measurement; Evolution and Equilibrium

SCIENCE AS INQUIRY: Abilities Necessary to Do Scientific Inquiry; Understanding About Scientific Inquiry

PHYSICAL SCIENCE: Interactions of Energy and Matter

LIFE SCIENCE: Interdependence of Organisms; Behavior of Organisms

SCIENCE AND TECHNOLOGY: Understanding About Science & Technology

Ocean Literacy Principles

For detailed descriptions, see pages 3–4 of this guide or the framework diagram at oceanliteracy.wp2.coexploration.org.

The ocean supports a great diversity of life and ecosystems. (5)

- Grades 6–8—B5 and B9
- Grades 9–12—C22, C27, and C28

The ocean and humans are inextricably linked (6).

- Grades 6–8—E1 and E6
- Grades 9–12—E6

Standards-alignment matrices are available on the DVD or at seaofsound.org.

Acknowledgments

By Susan Dodge M.S. Ed. and Elizabeth Rice, Ph.D., Creative Curriculum, for *Sea of Sound*. Art by Daniel Deibler. Edited by Marc Dantzker. Designed by Joanne Avila. Raven Lite was adapted for *Sea of Sound* by Timothy Krein. Sounds and advice provided by Ian Fein (Cornell University), Sheila Patek (University of Massachusetts), John Hoover, and Arthur Anker. If reproducing this version, please cite *Sea of Sound* as the source and provide the URL: seaofsound.org.

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BIODIVERSITY OF MARINE SOUND

Notetaking Chart: Teacher Version

Animal Sound Notetaking Chart

Name: _____

During this part of the video, you will learn about a variety of animal sounds in the ocean. Fill in the blocks of the chart as you learn about each animal.

Organism	Habitat	Why this organism creates underwater sound	How this organism creates underwater sound, and how they use it
Snapping shrimp	Reefs in tropical and temperate waters around the world.	To communicate, avoid predators, and kill prey	Cavitation; pressing the large claw together creates a jet of water that is moving so fast that it opens up a vacuum-filled hole (bubble) in the water. When the jet of water slows down, the vacuum-filled bubble collapses (implodes). The implosion makes the sound.
Soldierfish	Reefs	Alarm and other functions not shown in the video	Use sonic muscles connected to ribs, which are connected to swim bladder to produce sound. Sense sound using the swim bladder, which passes the signal to the ears.
Bearded seal	Under the ice around the Arctic Ocean	Underwater sound signals territoriality and social rank. (Possibly also mate attraction.)	Underwater, the seals' elastic airway radiates sound like a fish's swim bladder, but the structure that creates sound is still unclear.
Blue whale	Open ocean	To communicate and find mates across thousands of kilometers. (While we know that this is a classic mating call, and we know it can be heard thousands of kilometers away, scientists can't figure out how to "prove" that females are actually choosing males over those distances.)	(Anatomy not discussed in video); sound travels thousands of miles via sound channels, created by natural variations in speed of sound. This is called the SOFAR channel, and you can find out more about it at http://dosits.org and elsewhere.
Narwhal	Arctic oceans, under ice	Use echolocation to image the underwater environment and locate prey. (They also whistle and click to communicate, attract mates, coordinate movements, etc.)	Create intense clicks with a set of air sacs in their nasal passages (remember that their blow holes are their nostrils). They have an additional organ on their foreheads, the melon, which focuses sound, helping tighten it to a beam.

BIODIVERSITY OF MARINE SOUND

Notetaking Chart: Student Version

Animal Sound Notetaking Chart

Name: _____

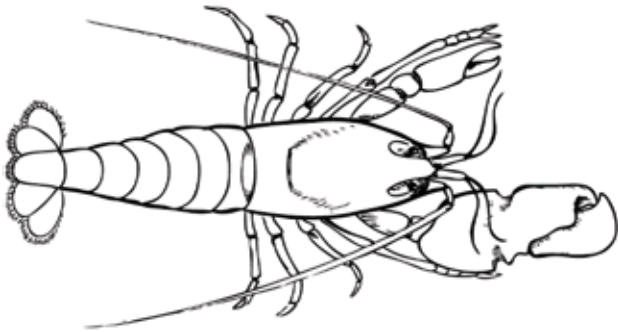
During this part of the video, you will learn about a variety of animal sounds in the ocean. Fill in the blocks of the chart as you learn about each animal.

Organism	Habitat	Why this organism creates underwater sound	How this organism creates underwater sound, and how they use it
Snapping shrimp			
Soldierfish			
Bearded seal			
Blue whale			
Narwhal			

BIODIVERSITY OF MARINE SOUND

Natural History and Anatomy—Shrimp

Anatomy and Natural History of Petroglyph Shrimp



Dive down to a Hawaiian reef and examine the coral as you swim. You see corals with wide, branched crevices between them. Listen. You hear snapping and popping. Chances are you'll never see the source of the sound, but you can try! Peer into the crevices and if you're lucky, you may find a petroglyph shrimp, *Alpheus deuteropus*, a type of snapping shrimp. How is it making that snap? And why?

Natural History

Petroglyph shrimp get their unusual name because of where they live. Found on reefs in Hawaii and the Indo-Pacific, the petroglyph shrimp live in crevices that look like petroglyphs, or ancient rock carvings. The crevices are formed on certain types of corals, such as lobe coral, hump coral, and knobby coral. Inside the crevices, the petroglyph shrimp live in deep burrows. The shrimp are often found in pairs within a crevice, with a male in one burrow and a female in another.

The petroglyph shrimp farm and eat filamentous algae found on the side of the crevices. Because they live secluded lives, petroglyph shrimp can be hard to find. Fish and other reef animals eat snapping shrimp when they can find them.



Petroglyph shrimp build crevices, the dark areas, in corals.

Like other snapping shrimp, petroglyph shrimp are small, growing to only 1.25 in (3.2 cm). They lack distinct color, but may be spotted with red. They are decapods, invertebrates with ten legs. Like other snapping shrimp in the family Alpheidae, the most distinctive feature of the petroglyph shrimp is its enlarged front claw that is modified to produce the snapping sound. One claw seems in proportion with the body while the other claw is much larger and can be held open.



The petroglyph shrimp is found in tropical waters from Africa to Australia.

Use of Sound

Some snapping shrimp use their snapping sound to capture their prey. For example *Alpheus heterochaelis*, the bigclaw snapping shrimp, uses its snaps to stun or kill small fish, small crustaceans, and worms which it then eats. *Alpheus californiensis* also use its snaps this way. After stunning or killing an organism, the shrimp will drag its prey back into its shelter to eat. However, it is unlikely that the petroglyph shrimp uses its snap for this reason simply because it has an abundance of food in the crevices it creates.

Snapping shrimp also use their snap to scare away predators or as a display of strength to intimidate potential rivals for mates or territories. During these types of interactions, the organisms are usually far enough away from each other—about 9mm—that the pressure waves from the snap are no danger to the opponent. Another filamentous algae-eating shrimp displays this behavior; *Alpheus frontalis* produced snaps when researchers tapped the tube it lived in.

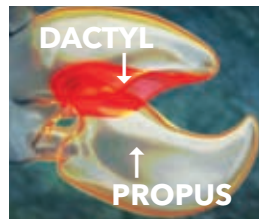
BIODIVERSITY OF MARINE SOUND

Natural History and Anatomy—Shrimp

Anatomy of Sound Production

Humans produce sound using the larynx to create vibrations and then modify sounds by altering the size and shape of our vocal tract. Snapping shrimp do something wildly different! Petroglyph shrimp, like other snapping shrimp, produce sound using their enormous claw. The huge claw is a remarkable adaptation, evolved from walking legs. A claw is made of a moveable upper dactyl and a propus, the non-moving lower part of the claw. The walking legs on a decapod have a moveable dactyl, but lack the lower propus. The claw evolved as the propus enlarged and elongated. As the shape changed, the function changed as well: from walking leg, to grasper, to crusher, and—in the case of snapping shrimp—to sound generator.

The large claw is usually held open. During the muscle contraction, the upper dactyl closes into the lower part of the claw. This quick movement forces the water out of the claw at very high speed (25 meters/second or 56 miles/hour). In that fast-moving jet of water the pressure decreases and the air bubble expands. But as the bubble immediately slows, it implodes, producing the loud “snapping” sound. The process is called cavitation and the pressure waves can stun or kill other organisms. The collapse of the bubble also produces an intense flash of light.



Sound production in snapping shrimp

elephas moves its antenna causing the plectrum, or soft tissue at the base of the antenna, to move over another file-like tissue near the eyes. This friction-based way of creating sound is thought to be a defense against predators.

Classification

- Kingdom: Animalia
- Phylum: Arthropoda
- Class: Malacostraca
- Order: Decapoda
- Family: Alpheidae
- Genus: *Alpheus*
- Species: *Alpheus deuteropus*

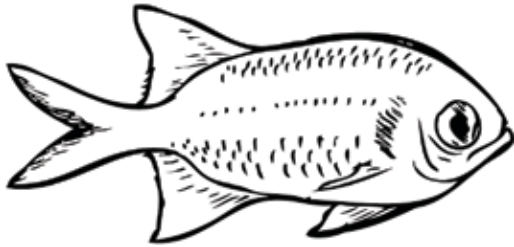
Diversity

The mechanism that the petroglyph shrimp uses to produce sound is unique to snapping shrimp. Other marine invertebrates, such as spiny lobsters and tropical sea urchins, produce sounds by rubbing two body parts together, a process called stridulation. The spiny lobster *Palinurus*

BIODIVERSITY OF MARINE SOUND

Natural History and Anatomy—Soldierfish

Anatomy and Natural History of the Epaulette Soldierfish



This little red fish on a Hawaiian reef wears its dark shoulder ornament like a soldier of distinction. Listen and you'll hear clicking sounds, a cadence coming from that little fish. We often think of fish as silent creatures, but the epaulette soldierfish is drumming away. How does it make that sound? And why?

Natural History

Also known as the shoulder-bar soldierfish, the epaulette soldierfish, *Myripristis kuntzei*, is distinguished by the dark bar that runs vertically from the top of the gill opening down to the pectoral fin, where you might imagine its "shoulder" would be. It reaches up to 20 cm in length, with red coloring on its back and silvery pink below.

The epaulette soldierfish is found in the tropical waters in the Indo-Pacific region, from South Africa to Australia, Indonesia, and into the western Pacific Ocean, including Hawaii. They live on reefs, 2 to 55 m deep. During the day, the fish congregate in large schools or hide in caves and crevices. The epaulette soldierfish is most active at night when it comes out to feed. Its big eyes are an adaptation to hunting in low light. These fish eat plankton, such as the larvae of shrimp, barnacles and crabs.

Epaulette soldierfish are prey for many other fish and mammals that live on and near tropical reefs. Humans also catch soldierfish. They are sometimes consumed as food and are popular aquarium fish.



The Epaulette soldierfish is found in tropical waters from Hawaii to Africa.

Use of Sound

The sounds generated by fish are a way for them to communicate with one another. Many fish live in a world where light travels poorly. Sound travels much better. Epaulette soldierfish don't make sounds that are very loud, but the drumming sounds are enough to warn others that there is a threat nearby.

Another fish in the same family, longspine squirrelfish *Holocentrus rufus*, produces sound in much the same manner as the epaulette soldierfish, but uses it in different ways. The longspine squirrelfish gives a single grunt to indicate an intruder in its territory, especially at dawn and dusk. They also create staccatos, or series of grunts, when certain predatory fish are nearby. However, the fish quiet down in the presence of most other predators, perhaps in an effort to hide. In one experiment, the echolocation click of a dolphin was played, and the squirrelfish grunts immediately quieted, presumably in an effort to avoid being eaten by the dolphin.

Hearing sound from their own species may also be important to young larval fish. This is an area of research where many experiments are being done today. In one study, the larvae of coral reef fish in a different family appear to use sound as a cue to determine where to settle.

Anatomy of Sound Production

Humans produce sound using the larynx to create vibrations and then modify sounds by altering the size and shape of our vocal tract. Fish do something wildly different!

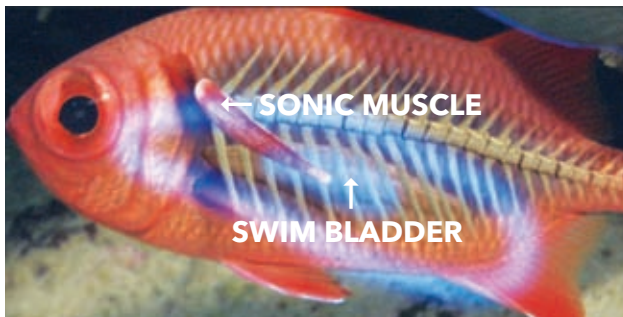
BIODIVERSITY OF MARINE SOUND

Natural History and Anatomy—Soldierfish

The epaulette soldierfish has specialized muscles, called sonic muscles, that stretch from the back of its head to its ribs. Inside the ribs is the swim bladder, a specialized air-filled organ that the fish uses to control its buoyancy in the water. However, the swim bladder has another purpose: to produce sound. The fish can flex its sonic muscles 100 times per second, which makes the swim bladder vibrate and resonate. The energy from the muscle is converted into sound energy. The sound radiates through the body wall into the water.

Classification

- Kingdom: Animalia
- Phylum: Chordata
- Class: Actinopterygii
- Order: Beryciformes
- Family: Holocentridae
- Genus: Myripristis
- Species: Myripristis kuntee



To make sound, the soldierfish vibrates its swim bladder using a specialized sonic muscle.

Diversity

Many types of fish in the family Holocentridae, as well as in other families, create sounds using the sonic muscle and swim bladder. For example the goliath grouper and black drum create drumming sounds with frequencies ranging from 45–60 Hz. Toadfish produce foghorn like sounds in the 250–300 Hz range.

Other fish produce sound using a completely different mechanism. Marine catfish and seahorses produce sound by stridulation, producing sounds with frequencies ranging from 100 Hz to 8,000 Hz. Stridulation occurs when objects are rubbed together. Some fish rub their teeth together. Others rub their pectoral fin spines against a bony arch near the fin. In some species, the swim bladder may help amplify the sound.

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Natural History and Anatomy—Bearded Seal

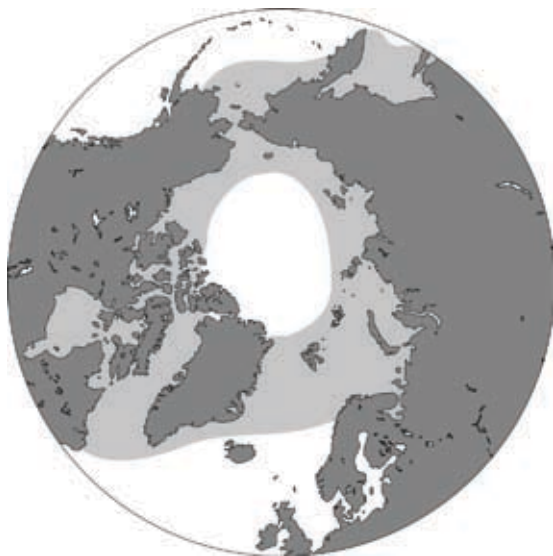
Anatomy and Natural History of the Bearded Seal



It's May in the Arctic; the pack ice begins to retreat. Suddenly an eerie song under the water replaces the silence. It's the trilling song of the male bearded seal, *Erignathus barbatus*. In the cold Arctic region, the bearded seals' songs herald the arrival of spring. How is this unusual sound created? And why?

Natural History

Bearded seals do indeed have beards. Around their mouths are the whiskers that give them their name. These pinnipeds have a rectangular body shape and relatively small heads. Adults are usually gray or dark brown with lighter spots. They can weigh up to 34 kg and are approximately 2–2.5 m in length. Females tend to be slightly larger than males. Bearded seals have strong claws on their front flippers. They need their claws to make breathing holes in the ice.



The bearded seal is found in arctic waters around the Northern Hemisphere.

Bearded seals live throughout the shallower waters of the Arctic, moving seasonally to avoid thick ice. During the winter months, they move southward. As spring arrives, they start moving to higher latitudes again. They spend most of their lives in the water, occasionally hauling out onto the ice. The seals are fairly solitary creatures, although sometimes they are found in groups.

They feed on the shallow sea floor, rarely diving more than 100 m to find the fish, mollusks, crabs, worms, and amphipods they eat. In turn, they are prey for polar bears, orcas, walruses, and Greenland sharks.

Humans are also predators of bearded seals. Native peoples hunt them for food and leather; a few thousand of the seals are taken each year. In the 1960s and 1970s, however, Soviet fishermen took large catches of tens of thousands of bearded seals. Quotas were introduced and the catch is now much lower. The bearded seal population is probably in the hundreds of thousands today and is not considered endangered.

Use of Sound

Bearded seals have a variety of vocalizations. For example, young pups vocalize so they can reunite and nurse after the mother has been diving for food. However, it is the underwater songs of the male bearded seals that are completely unique. The songs are extended trills that last about one minute and decrease in pitch as they go on.

After the pups are weaned and the mating season begins, male bearded seals begin their most active underwater singing. The males sing to defend their territories and to establish their social rank. Males with

longer trills have an established territory. Lower ranking males, with shorter trills, will approach higher-ranking singing males and rub up against them. The calls are stereotyped—or follow the same pattern—and range from 0.02–11 kHz.



BIODIVERSITY OF MARINE SOUND

Natural History and Anatomy—Bearded Seal

Interestingly, the songs vary—sung in dialects in different geographical regions.

The songs may also be signals to females about the quality of a male as he tries to attract a mate. The songs of the male bearded seals can be heard more than 10 km away. Because females often roam as they forage for food, it's important that the trilling songs carry long distances for the females to hear.

Anatomy of Sound Production

A bearded seal has a respiratory tract similar to that of humans. A seal breathes through its mouth, and has a larynx, trachea, and lungs. However, because these animals dive into deeper water—with deeper pressure—their respiratory structures have evolved to facilitate diving. Their tracheas are wider and their airways are made of flexible cartilage and membranes.



In addition, the bearded seal also has a dorsal tracheal membrane that extends behind the trachea all the way to the lungs. It is this membrane that can inflate, similar to the swim bladder in a fish, and can resonate and radiate the male's underwater song. The male doesn't appear to be exhaling while making this call; the air is probably recycled back into the lungs. What is unclear, however, is where the sound originates.

Pinnipeds can also create sounds in the air using the larynx as the source of the vibration, very similarly to the way humans vocalize. Seal barks, howls, and cries can be produced as air leaves the lungs and passes over the vocal folds in the larynx. Differences in the sound can be created by the air sacs in the head or by changing the shape of the mouth, in the same way humans modify sound.

Diversity

Although male bearded seals produce a wonderful, unique song, there are other pinnipeds that create equally interesting vocalizations. The male hooded seal, for example, has a specialized red elastic nasal septum that comes out through the seal's nostril and puffs up while the seal makes a variety of sounds. Male ribbon seals also have a sac connected to the trachea. California sea lions make a variety of clicks and barks underwater without releasing any air. Walruses create a wide variety of sounds, including whistles and gong-like sounds.

Classification

- Kingdom: Animalia
- Phylum: Chordata
- Subphylum: Vertebrata
- Class: Mammalia
- Order: Carnivora
- Suborder: Caniformia
- Family: Phocidae
- Genus: *Erignathus*
- Species: *Erignathus barbatus*

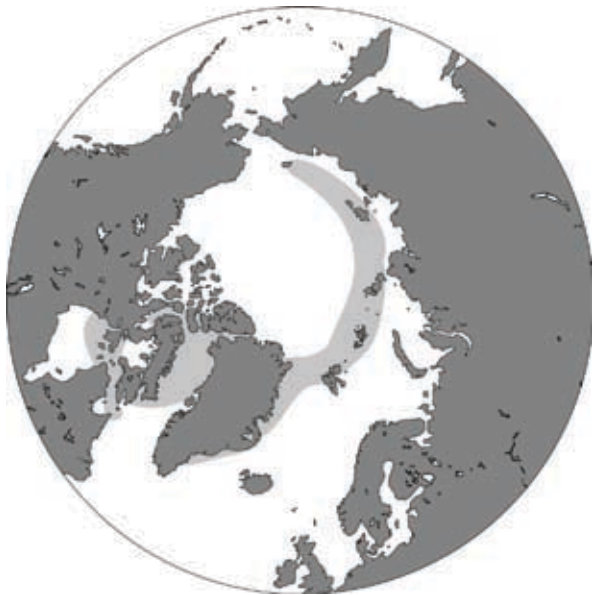
BIODIVERSITY OF MARINE SOUND

Natural History and Anatomy—Narwhal

Anatomy and Natural History of the Narwhal



A unicorn in the ice? Narwhals, toothed whales found in Arctic waters, are thought to be the inspiration for European stories about mythical unicorns. But as scientists learn more about these fascinating animals and the sounds they create, we leave the land of fairy tales to find the answers to the questions we can pose. How do they create their clicks? And why?



The narwhal is found in arctic waters around the Northern Hemisphere.

Natural History

The narwhal, *Mondon monoceros*, is an odontocete, a toothed whale. Its tusk is really a giant tooth. On its upper jaw, a narwhal has two teeth that elongate. In most females the teeth stay in the skull. On most males the left tooth grows through the jaw bone and the skin, twisting to a length of 2 m. The tusk may be used for vibration detection, hunting, mate selection, male-male aggression, sensing the salinity or temperature of water, or making holes in ice. The tusk is clearly not essential, since many survive without one. Instead, it likely evolved as a secondary sexual characteristic in males, like the feathers in a peacock's tail.

Narwhals are born gray or brown-gray, but their skin color changes with age, transitioning from gray to black to white. Narwhals have no fin on the back, allowing them to navigate under ice. Their body length is usually 4–5 m and they range in weight from 900 kg to 1,600 kg. Males are generally larger than females.

Narwhals live together in small, gender-segregated groups (5–10 whales) and migrate in larger groups (typically 20–30, but can be as many as 1,000 animals). These unusual whales live in the cold waters of the Arctic, preferring to stay close to the pack ice and deep water. There are an estimated 40,000 narwhals. The largest populations are on the western side of Greenland and into Canada, but narwhals also live east of Greenland and north of Scandinavia and Russia. They migrate seasonally, moving into deeper water at the edge of the continental shelf when coastal areas freeze.

What—and how much—narwhals eat seems to vary depending upon the season. Their diet consists of squid, crustaceans, and various fishes including herring, flounder, cod, Greenland halibut and salmon. During winter months, narwhals tend to go farther offshore and do deeper dives; one recent study suggests that the whales consume more in the winter.

Despite the intimidating tusks on the males, narwhals are prey for other animals, including orcas, Greenland sharks, and polar bears. Humans are also predators. Inuit people eat narwhals and consider the skin, known as mattak, a delicacy. Tusks are sometimes kept as trophies or sold as curios.

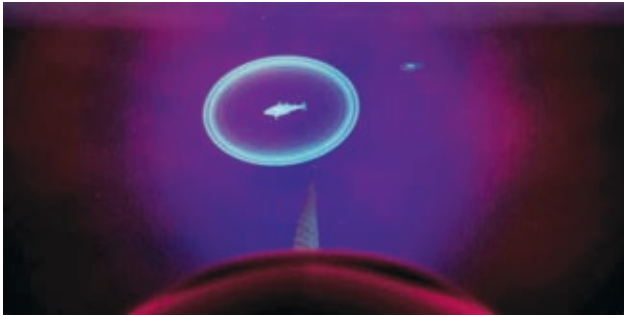
Use of Sound

Narwhals produce clicking sounds, which they use for echolocation. In the same way that bats navigate a night-darkened world, narwhals send out high frequency sound into the dark waters around them. When the sound waves hit a nearby object, some are reflected back towards the narwhal. The animal senses the returning waves and is able to determine where, how far away, and how large an object is.

Narwhals also produce a variety of click patterns at different speeds and frequencies. The slower click series, 3–10 clicks per second, is likely used while searching for prey. The faster series, 100–150 clicks per second, is likely used as a narwhal closes in on its prey. The clicks are higher than human ears can hear, varying in frequency from 20 kHz to 100 kHz. They can be as loud as 218 dB.

BIODIVERSITY OF MARINE SOUND

Natural History and Anatomy—Narwhal

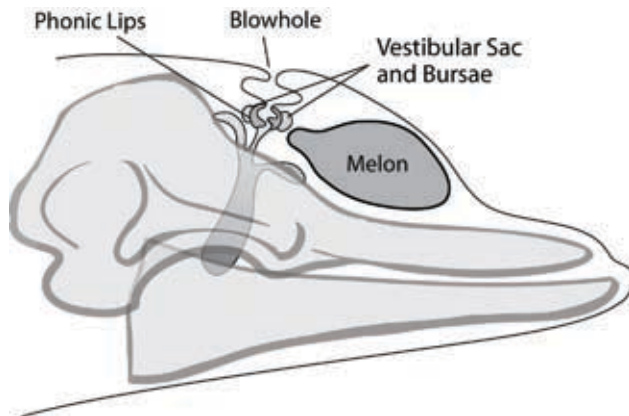


Echolocation clicks bounce off the air-filled swim bladders inside the fish.

Narwhals also use vocalizations, probably for communication and identification of group members. They create long pulsed tones, lasting up to several seconds, with frequencies of 500 Hz to 24 kHz. They also make long, sliding whistles lasting up to 6 seconds with frequencies of 300 Hz to 18 kHz.

Anatomy of Sound Production

We humans produce sound by using our larynx to create vibrations and then modify sounds by altering the size and shape of our vocal tract. Toothed whales, in contrast, have evolved different structures and mechanisms to produce sound. Because the anatomy of sound production in narwhals has not been studied extensively, we need to look at a close relative to learn about how sound is produced. The bottlenose dolphin provides insights that we will apply to the narwhal.



Most toothed whale vocalizations are produced in the nasal passages. Close to the blowhole are structures called the vestibular sac and the bursae. Part of those bursae, called the phonic lips, extends into the nasal passage. Rather than breathing out to make the sound, these animals recycle the air via the vestibular sac.

The phonic lips are thought to be the origination point of the sounds that toothed whales make. When air passes the phonic lips, they slap together and cause vibrations. The sound is then directed out of the body via the melon, a mass of fatty tissue above the jaw, which focuses the sound, a critical element of echolocation. The odontocetes have two sets of phonic lips, which can be operated independently.

Diversity

Odontocetes, or toothed whales, probably all use echolocation, which involves making clicks. In addition, most toothed whales produce a variety of other types of clicks and whistles for communication. Many species of dolphins, for example, produce complex signature whistles that they use to identify themselves and others. Killer whales, which make clicks and whistles, live in small stable groups—each group has its own dialect.

While each of the different odontocetes has similar anatomy to that described above, there is variation among the species. Particular anatomical parts are different sizes or arranged slightly differently. For example, sperm whales, which have loud and complicated clicks, have heads that are disproportionately large. Belugas are able to modify the shape of their melon.

Classification

- Kingdom: Animalia
- Phylum: Chordata
- Subphylum: Vertebrata
- Class: Mammalia
- Order: Cetacea
- Suborder: Odontoceti
- Family: Monodontidae
- Genus: *Monodon*
- Species: *Monodon monoceros*

BIODIVERSITY OF MARINE SOUND

Natural History and Anatomy—Blue Whale

Anatomy and Natural History of Blue Whale

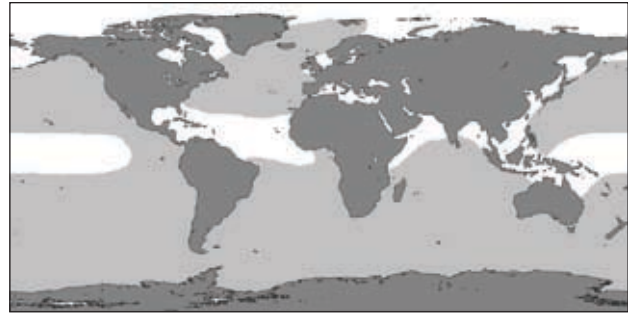


Blue whales, the ocean's giants, live alone a lot of the time. Loners they may be, but quiet they are not! They produce low, deep sounds that carry great distances in the ocean. Why do they create sounds? How exactly do they make them? Scientists are still trying to fully answer these questions.

Natural History

Blue whales, *Balaenoptera musculus*, are enormous animals that eat tiny, tiny creatures. Blue whales are baleen whales; their mouths are filled with baleen, not teeth. The thin baleen plates are made of keratin and function as a sieve or filter. (Your hair and nails are made of keratin too!) A blue whale dives no more than 100 meters into school of krill, opens its mouth, and gulps in water. After closing its mouth, the whale forces the water out and the tiny krill and other small organisms catch in the baleen plates. A single blue whale may eat as much as 5,500 kg of krill each day. That's the mass of an elephant or a pickup truck.

Krill are found in all the world's oceans and so are blue whales, with distinct populations in the Northern and Southern hemispheres. Most blue whales move to different parts of the ocean in different seasons. During warmer months they move to higher latitudes, closer to the poles. During cooler months they move to subtropical latitudes. They usually travel alone or in small groups, but sometimes they're seen in larger groups of 60 or more.



Blue whales are found in all the world's oceans.

Blue whales are the largest creatures on Earth, reaching 33 m. Females are slightly larger than males; males tend to be up to 3 m shorter. The whales are blue-gray, but their undersides can sometimes become yellowish because diatoms, a type of algae, cover them.

Blue whales, by virtue of their size, are relatively safe from predators. However, there are records of orca attacks on blue whales. The greatest threat to blue whales comes from humans. Blue whales were hunted extensively in the 20th century. Researchers estimate that before hunting, there were more than 150,000 blue whales, but today only about 6,000 remain in the oceans. Today there is an international ban on hunting blue whales; they are considered endangered.

Use of Sound

For animals living in water there are strong selection pressures to use sound—rather than sight or scent—as a primary means of communication. Light travels poorly in water while sound propagates very well. Blue whales produce a variety of low frequency sounds. Their long calls usually last 10–30 seconds and have a frequency in the range between 10–40 Hz—partially below frequencies detected by the human ear. At certain depths and pressures, the water may create a sound channel that will carry these low frequency sounds hundreds of kilometers.

BIODIVERSITY OF MARINE SOUND

Natural History and Anatomy—Blue Whale



Blue whale sounds can travel extremely long distances.

The sounds, which can travel extremely long distances, are likely used to communicate with other whales of the same “herd” that may be hundreds of kilometers away. This is particularly important because blue whales are usually solitary creatures. Males may make their low, repetitive calls to attract females as mates.

Anatomy of Sound Production

Whales evolved from land-dwelling mammals 55 million years ago. Whales retain the defining characteristics of mammals, including breathing air with lungs, birthing live offspring, and nursing their young. However, many structures found in land mammals have been modified so that whales can live in the ocean environment. For example, rather than nostrils, whales have a blowhole on the top of their head. The blue whale’s head has nasal cavities just below the blowhole. The blowhole connects via nasal passages to the larynx, trachea, and lungs. The blue whale has an additional structure, the diverticulum, a sac that opens into the cartilage of the larynx.

We humans produce sound by using our larynx to create vibrations and then modify sound by altering the size and shape of our vocal tract. Blue whales, in contrast, have evolved different structures and mechanisms to produce sound. Researchers have proposed a model in which air is exhaled from the lungs and flows through a valve that creates the pressure changes in the nasal cavities. The laryngeal sac and the nasal passages amplify the sound. The exact location of the proposed valve is unknown, but it may be in the larynx.

Diversity

Other baleen whales create a wide variety of different sounds. Humpback whales are well known for their complex songs. Their songs range in frequency from 20 Hz to 10 kHz, lasting a few minutes to 48 hours long. Minke whales, on the other hand, make a few distinct vocalizations, one of which, a downsweep from 250 Hz to 50 Hz, lasts only a fraction of a second. Gray whales are most vocal during mating season and their sounds are described as knocks, boings, moans, and grunts.

Classification

- Kingdom: Animalia
- Phylum: Chordata
- Subphylum: Vertebrata
- Class: Mammalia
- Order: Cetacea
- Suborder: Mysticeti
- Family: Balaenopteridae
- Genus: Balaenoptera
- Species: Balaenoptera musculus



BIODIVERSITY OF MARINE SOUND

Natural History and Anatomy Worksheet: Teacher Version

Natural History and Anatomy of Sound

1. Draw or describe how your organism uses its specialized anatomical structures to produce sound.

- **Snapping shrimp:** *There are hundreds of species of snapping shrimp. They all use their huge front claws to produce a cavitation bubble that implodes and produces the snap sound. The claw squeezes out a jet that is so fast that (according to Bernoulli's principle) the pressure drops low enough that tiny micro-bubbles of air that are always present in oxygenated water rapidly expand. The bubbles are basically vacuum-filled, so as the speed of the water decreases, the bubble collapses on itself. The collapse is very rapid and it creates pressure waves in the water, which we hear as sound.*
- **Epaulette soldierfish:** *The fish flexes its sonic muscles 100 times per second, which makes the swim bladder vibrate and resonate.*
- **Bearded seal:** *The structure in which the underwater song of the male originates is unknown. What we do know is that the tracheal membrane inflates while they vocalize. It is likely that, like a fish's swim bladder, it resonates and radiates the underwater sound.*
- **Blue whales:** *Researchers have proposed a model in which air is exhaled from the lungs and flows through a valve that creates the pressure changes in the nasal cavities. The laryngeal sac and the nasal passages amplify the sound.*
- **Narwhal:** *Sounds are thought to originate at the phonic lips, a structure in the nasal passages of the whale. When air passes the phonic lips, they slap together and cause vibrations. The sound is then directed out of the body via the melon.*

2. How is the way your model organism produces sounds similar to or different from the way humans produce sound?

- **Humans:** *produce sound using our larynx to create vibrations and then modify the sounds by altering the size and shape of our vocal tract.*
- **Petroglyph shrimp:** *use their huge claw—very different!*
- **Epaulette soldierfish:** *use their sonic muscles and swim bladder; it's very different.*
- **Bearded seal:** *The male produces the song using its respiratory system, like a human, but the anatomy of a bearded seal is different. Above water, where it opens its mouth and exhales while calling, its system probably works just like ours. But underwater, it doesn't exhale to make that amazing sound so it can't be using its voice box (larynx). We do know that the bearded seal inflates a tracheal membrane and that this probably resonates and radiates the sound. But we don't know what starts the vibrations.*
- **Blue whale:** *Sound production, like that in humans, involves the respiratory system. The sound originates near the larynx, but blue whales use different anatomical structures than humans. The whale doesn't open its mouth to make sound, so it needs to hold onto its air and recycle it in order to make long calls at depth without getting more air.*

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Natural History and Anatomy Worksheet: Teacher Version

- **Narwhal:** *Sound generation in the narwhal is very different; the sound originates in the upper airways, not the larynx. It doesn't open its mouth to call. Instead its sounds are radiated through its forehead. It uses an organ called a melon to focus that sound into a beam. This is how echolocation clicks are made. It also seems to be able to make whistles and other sounds at the same time, so it may have other sound structures.*

3. Describe the sounds that your animal makes, using words and/or numbers.

- **Snapping shrimp:** *makes a loud (200 dB) snap.*
- **Epaulette soldierfish:** *makes drumming sounds and clicks.*
- **Bearded seals:** *have a variety of vocalizations. Young pups vocalize to their mothers. Males sing songs that are extended trills, lasting about one minute and decreasing in pitch as they go on.*
- **Blue whales:** *produce a variety of low-frequency sounds. Their long calls usually last 10–30 seconds and have a frequency in the range of 10–40 Hz. (The sound we heard in the video was sped up so we could hear it. In reality, the sound is so low that it is outside our range of hearing. If you were close enough, you could feel it, but you still couldn't hear these frequencies.)*
- **Narwhals:** *produce a variety of click patterns at different speeds and frequencies. They also make whistles and other social sounds.*

4. How does your organism use the sounds it produces?

- **Petroglyph shrimp:** *use the snap to scare predators, defend territory, and to stun or kill small prey.*
- **Epaulette soldierfish:** *use drumming sounds to warn others that there is a threat nearby. They also probably use sound for other functions.*
- **Male bearded seals:** *sing to defend their territories and to establish their social rank. Males who have territories tend to have longer calls. This implies that either more fit males can make longer calls, or that longer calls signal territorial ownership.*
- **Blue whale:** *sounds, which travel far, are likely used to communicate with other whales that may be hundreds of kilometers away. This is particularly important because blue whales are usually solitary creatures. Males may make their low, repetitive calls to attract females as mates. While scientists are sure that the sound travels that far, and that animals move over those ranges, they can't actually be sure that animals specifically choose mates over those distances. There's no way to do controlled experiments and the time scale of the interactions take weeks to play out.*
- **Narwhals:** *use clicks for echolocation and other vocalizations for communication and identification of group members.*

5. Is the animal's sound well suited to its purpose? Why or why not?

Student answers will vary. Accept all logical and reasoned answers. For example:



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Natural History and Anatomy Worksheet: Teacher Version

- **Snapping shrimp:** *The snapping shrimp make a loud sound to scare away other animals. If the purpose of the sound is to seem intimidating and strong, then the loud sound makes sense. Because the other animal is nearby, the sound does not need to travel very far.*
- **Soldierfish:** *create drumming sounds to defend their territories. The sound seems reasonable for its purpose—a way to say, “It’s mine,” over and over again. But why wouldn’t they drum out their own individual patterns? Would it be better to have a lower sound that traveled farther?*
- **Bearded seal:** *The eerie wailing songs of male bearded seals are mind-boggling! If longer calls mean “I’m stronger and better than you,” then it makes sense that the length of the call matters, because the calls likely establish social rank.*
- **Narwhals:** *live under the ice, where it’s very dark. Still they must find food. Echolocation seems like an effective way to find things. It’s a more logical choice than using vision in a dark place.*
- **Blue whale:** *The blue whales make repetitive low-frequency calls. If they are trying to communicate with other whales thousands of kilometers away, a far-travelling, low-frequency sound makes sense.*

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Natural History and Anatomy Worksheet: Student Version

3. Describe the sounds that your animal makes, using words and/or numbers.

4. How does your organism use the sounds it produces?

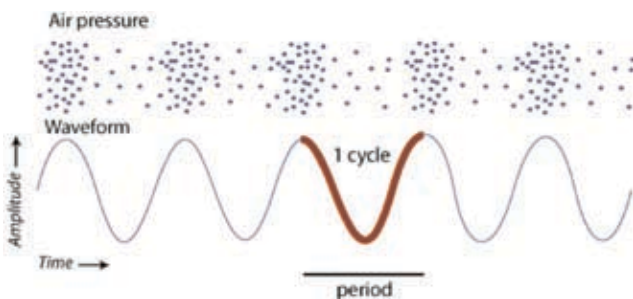
5. Is the animal's sound well suited to its purpose? Why or why not?

BIODIVERSITY OF MARINE SOUND

Analyzing Animal Sound

The ocean is filled with sounds from animals, weather, earthquakes, ships, sonar, and air guns, among others. One way to study sound is to listen. To listen to sound underwater scientists use hydrophones (underwater microphones), which convert sound energy into electrical energy, so sounds can be played back later or analyzed. Scientists are trying to understand what animals make sound and where, as well as how and why sounds are made.

Sound is a form of energy that travels in mechanical waves. When an object vibrates, the molecules of the surrounding medium—whether air or water—are temporarily compressed, then expand again, and a sound wave is formed. A sound wave is a longitudinal wave.



In water, sound speed varies with the water's temperature, depth (pressure), and salinity. Sound speed in air is less variable. Sound also travels faster in water (approximately 1,500 m/s) than in air (approximately 350 m/s). These aspects of the physics of sound in water combine to form a fascinating ocean feature called the Sound Fixing And Ranging—SOFAR—channel. It exists at approximately 1,000m below the surface and allows low-frequency sounds to slowly travel great distances.

Analyzing Sound

Raven Lite is a simplified version of software used by scientists to analyze sound. This software provides a visual representation of sound to help us examine its characteristics. The top panel is the waveform, a graph showing sound pressure changes over time. The lower panel, the spectrogram, translates information from the waveform into a visual representation of

frequency over time. The spectrogram's color gradient also shows intensity; louder sounds are brighter. However, it's important to note that loudness is referenced to a different standard in water than it is in air, so loudness between the two can't be easily compared.

What might scientists want to examine using sound analysis software? One characteristic to examine is the amplitude, or height, of the sound wave. Higher amplitude means there's more pressure and therefore a louder sound. Another feature to examine is the frequency, or the rate at which wavelengths pass a given point. Higher frequency sounds have higher pitch. Yet another feature is the duration of the sound. For example, some whales make very long sounds while others' sounds are much shorter. How might the duration of the sound be related to the sound's purpose?

Humans and Sound

- Human speech ranges from ~80-15,000 Hz with most energy below 8,000 Hz
- Humans can hear from 20 Hz to 20,000 Hz.
- The level of loudness that humans perceive varies with the frequency of the sound.

BIODIVERSITY OF MARINE SOUND

Analyzing Animal Sound Activity

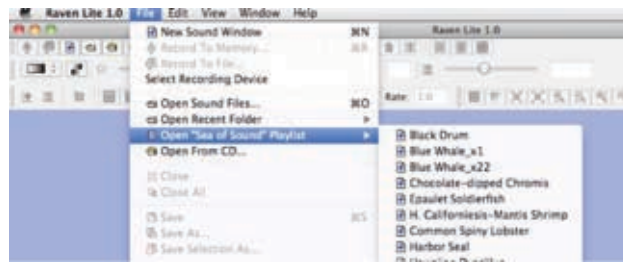
Part 1: Listen and Repeat

Can you imitate the sounds of marine creatures? Animals in the ocean make lots of different noises! Some are loud; some are quiet. Some are so high-pitched we can't hear them. Others have such low frequencies that we can't hear them either. But many are right in the range of human hearing.




Listen to and imitate three different sounds. Use the Raven Lite Guidesheet for help. Record your data in the chart on the **Question Sheet**.

Directions

1. In Raven Lite, under "File" / "Open Sea of Sound Playlist," you will find all the sound files you need.



2. Play each sound. Describe it in words in the chart on the Question Sheet. Then measure its duration, range of strong frequencies, and maximum intensity.
3. Imitate the sound! Use Raven Lite to record your version and then measure the duration, range of strong frequencies, and maximum intensity of your sound.

	<p>Blue whales call to communicate over long distances. Their calls are so low that you can barely hear them, and you might need a subwoofer to play them back.</p>	<p>Open "Blue Whale x1" to hear the real call. Then open "Blue Whale x22" to hear it sped up.</p>
	<p>Some snapping shrimp use their snaps to scare off competitors and defend their territories; others use the snap to stun prey. If you can't do this with your mouth, try using something else (sticks, fingers, etc.).</p>	<p>Open "Snapping Shrimp-Many" to hear the sounds of a reef with thousands of shrimp. Then open "Petroglyph snapping shrimp" to hear one individual. Measure and imitate this one.</p>
	<p>Male Weddell seals, which live around Antarctica, produce eerie underwater songs to attract females and warn off other males.</p>	<p>Open "Weddell Seal" and do your best to mimic this melody too.</p>

BIODIVERSITY OF MARINE SOUND

Analyzing Animal Sound Worksheet: Teacher Version

Analyzing Animal Sound Question Sheet

1. What tools do researchers use to collect and analyze underwater sounds?

Researchers use hydrophones (special underwater microphones) to hear and collect marine sounds. Sound analysis software is used to visualize and analyze the sounds.

2. In Raven Lite, what does the upper portion of the window show you? What are the axes in that section?

The top portion of the window shows the waveform. Amplitude (in kU) on the y-axis is plotted against time (in seconds), on the x-axis.

Note that kU is just a generic kilo unit. Since you don't have a reference for loudness, you can't set these in terms of an actual pressure. If you had a test tone of a given loudness at a known distance, then you could convert this to dB/re ___ or something more meaningful.

3. In Raven Lite, what does the lower portion of the window show you? What are the axes in that section?

The bottom portion of the window shows the spectrogram. Frequency (in Hz or kHz) on the y-axis is plotted against time (in seconds) on the x-axis.

Imitating Ocean Sounds

Try creating the sounds below—the sounds that different marine animals make—and then make some measurements of the sounds.

	Description of sound	Duration of sound (seconds)	Minimum Frequency (Hz or kHz)	Maximum Frequency (Hz or kHz)	Loudest Frequency (Hz or kHz)
Blue whale x1 speed or x22 speed		x1 is an excerpt 130 seconds long, x22 is 47 seconds long so actually more than 17 minutes realtime.	x1 is 13 Hz, x22 is 280 Hz. *Note these are the same value when corrected for the play-back speed.	x1 is 20 Hz, x22 shows overtones up to 2 kHz. The overtones are absent in the x1 file.	x1 is 16.5 Hz, x22 is ~360. *Note these are the same value when corrected for the play-back speed.
You as a blue whale					

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Analyzing Animal Sound Worksheet: Teacher Version

Petroglyph snapping shrimp many or individual		<i>Individual pops are 0.01 seconds long, or 10 milliseconds.</i>	<i>Impulsive sounds have energy across a wide band. minimum is near 0 Hz.</i>	<i>The maximum appears to be 20 kHz, but this is largely an artifact of the recording.</i>	<i>There isn't one.</i>
You as a snapping shrimp					
Weddell seal		<i>45 seconds</i>	<i>90 Hz</i>	<i>Peters out above 16 kHz</i>	<i>The loudest part of the pops and chirps varies. The loudest part of the sweep is between 1-1.7 kHz.</i>
You as a weddell seal					

4. How were the three animal sounds different from one another? Use the terms frequency, amplitude, and duration in your answer.

Answers to 3, 4 and 5 wait for the new sound file.

5. Evaluate how well you were able to replicate the sample sounds. Which of the following was hardest to match (intensity, range of strong frequencies, and duration)? Why do you think this was?

Student answers will vary.

6. What are the weaknesses of the way we collected data from the sounds?

Hopefully, students will note that the data they were taking is somewhat arbitrary. Although they were to follow a procedure, they probably had to make judgment calls along the way. The procedures we used are not rigorous enough to stand up to scientific scrutiny, but they do allow students to get a sense of the different ways to quantify sounds.

7. Which animal sound did you find most interesting? Why?

Student answers will vary.

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Analyzing Animal Sound Worksheet: Student Version

Analyzing Animal Sound Question Sheet

1. What tools do researchers use to collect and analyze underwater sounds?
2. In Raven Lite, what does the upper portion of the window show you? What are the axes in that section?
3. In Raven Lite, what does the lower portion of the window show you? What are the axes in that section?

Imitating Ocean Sounds

Try creating the sounds below—the sounds that different marine animals make—and then make some measurements of the sounds.

	Description of sound	Duration of sound (seconds)	Minimum Frequency (Hz or kHz)	Maximum Frequency (Hz or kHz)	Loudest Frequency (Hz or kHz)
Blue whale x1 speed or x22 speed					
You as a blue whale					

BIODIVERSITY OF MARINE SOUND

Analyzing Animal Sound Worksheet: Student Version

Petroglyph snapping shrimp many or individual					
You as a snapping shrimp					
Weddell seal					
You as a weddell seal					

4. How were the three animal sounds different from one another? Use the terms frequency, amplitude, and duration in your answer.
5. Evaluate how well you were able to replicate the sample sounds. Which of the following was hardest to match (intensity, range of strong frequencies, and duration)? Why do you think this was?
6. What are the weaknesses of the way we collected data from the sounds?
7. Which animal sound did you find most interesting? Why?

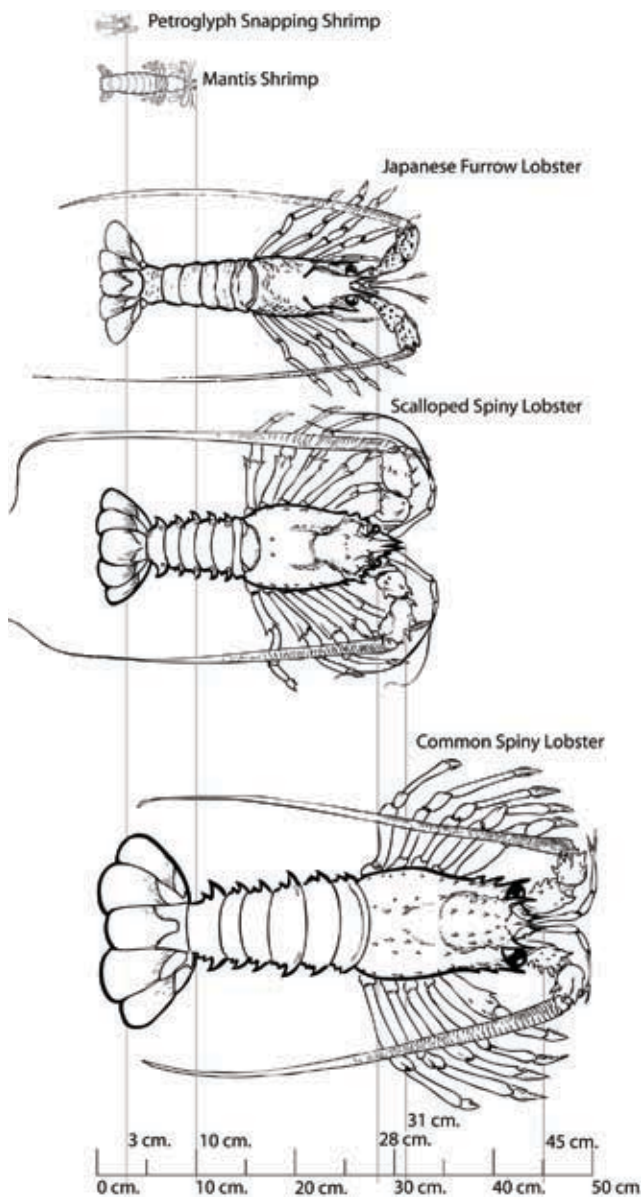


BIODIVERSITY OF MARINE SOUND

Analyzing Animal Sound Activity

Part 2: Exploring the Sounds of Marine Invertebrates

Marine invertebrates produce a variety of sounds in a variety of different ways.



- A petroglyph shrimp snaps its enlarged front claw together to create a cavitation bubble that then explodes in the water, producing the “snap.” Some snapping shrimp snap to defend their territories, while others use the snap to stun prey.
- Spiny lobsters produce sounds by rubbing two body parts together, a process called stridulation. The spiny lobster moves its antenna causing the plectrum, or soft tissue at the base of the antenna, to move over another file-like tissue near the eyes. This friction-based way of creating sound is thought to be a defense against predators.
- Mantis shrimp make very low rumbling sounds. The sounds, produced by muscles vibrating near the edge of the carapace, or hard outer covering, Scientists have suggested that they use their sounds to both scare off predators and to interact socially with other mantis shrimp.

Directions:

Open the sounds of these five animals in Raven Lite. Listen carefully and examine the spectrograms of each species.

BIODIVERSITY OF MARINE SOUND

Analyzing Animal Sound Worksheet: Teacher Version

Part 2: Exploring the Sounds of Marine Invertebrates

1. How is the use of invertebrate sounds similar?

Invertebrates create a wide variety of sounds—snaps, rasps, and low rumbles—for defense. Though some species use sound for other purposes (predation, social interactions), they have sound-based self-defense in common.

2. Listen to each species sound from the Sea of Sound play list. What differences do you hear and see between the species? Can you relate the differences you hear to the method the animal uses to produce sound?

The snap of a snapping shrimp sounds very different from the rasp of a lobster. However, the rasps of different lobsters sound only subtly different from one another. This makes sense, since the cavitation bubble of a shrimp produces sound by a completely different mechanism than the stridulation (rasp) of a lobster. However the rasping of two different lobsters share a common mechanism of production, and therefore sound more similar.

3. Focus on the three lobster species. Can you see or hear a trend that relates to their anatomy body size? Do the shrimp fit that pattern? Why or why not?

Larger lobsters have lower frequency sounds just like larger hair combs are lower pitched than smaller ones. The shrimp don't have the same relationship. That's because they make sound in a totally different way.

4. Why might there be an evolutionary advantage to producing low-frequency (low-pitched) sounds?

Think of the blue whale again. Low-frequency sounds travel farther. A far-reaching sound can reach more mates, predators, and prey. Therefore, when distance matters, there is strong evolutionary pressure to use the lowest sound physiologically possible. Usually (but not always), larger animals are able to make lower frequency sounds than smaller animals, so you see relationships as in the three lobster species.

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Analyzing Animal Sound Worksheet: Student Version

Part 2: Exploring the Sounds of Marine Invertebrates

1. How is the use of invertebrate sounds similar?
2. Listen to each species sound from the Sea of Sound play list. What differences do you hear and see between the species? Can you relate the differences you hear to the method the animal uses to produce sound?
3. Focus on the three lobster species. Can you see or hear a trend that relates to their anatomy? Do the shrimp fit that pattern? Why or why not?
4. Why might there be an evolutionary advantage to producing low-frequency (low-pitched) sounds?

BIODIVERSITY OF MARINE SOUND

Student Handout: Raven Lite Guide

Full documentation at www.birds.cornell.edu/brp/raven/RavenDocumentation.html

At-a-glance guide to Raven Lite

Menu (Raven Lite 1.0 File Edit View Window Help)

Toolbar (Icons for file operations, playback, and zoom)

Sound (Main display area showing waveform and spectrogram)

Playback Controls (Play, Stop, Speed)

Spectrogram Controls (Brightness, Contrast, Detail)

Zoom options (Zoom in, Zoom out, Reset)

Waveform (Top view of the audio signal)

Spectrogram (Bottom view of frequency over time)

Measurement bars (Drag the purple lines to desired point in time, frequency or amplitude and read result on the axis (in blue))

Time (Horizontal axis for both views)

Loudness (Amplitude) (Vertical axis for waveform view, in kU)

Pitch (Frequency) (Vertical axis for spectrogram view, in kHz)

Time: 16.482 S Minimum: -2427 Maximum: 2318

BIODIVERSITY OF MARINE SOUND

Student Handout: Raven Lite Recording Guide



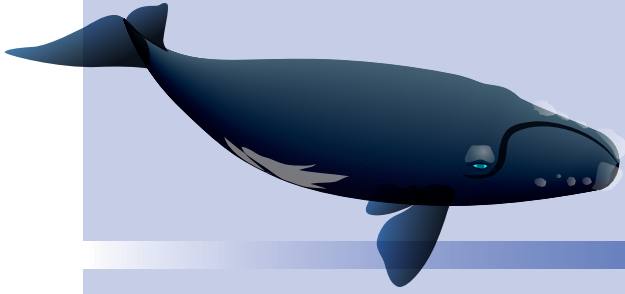
How to record

Make sure your computer has a microphone plugged in and working by choosing one of the microphone icons from the toolbar and then beginning a recording (see below). If you do not see changes in the upper blue graph as you speak, check the audio options on your computer.

The screenshot shows the Raven Lite 1.0 software window. The top menu bar includes 'Raven Lite 1.0', 'File', 'Edit', 'View', 'Window', and 'Help'. Below the menu is a toolbar with various icons for recording, editing, and playback. The main window is divided into two panes: 'Waveform' on the left and 'Spectrogram' on the right. The waveform shows amplitude over time, and the spectrogram shows frequency (kHz) over time. The spectrogram has a vertical axis from 0.000 to 30 kHz and a horizontal axis from 0 to 36.6 seconds. A 'Not recording.' indicator is visible at the bottom right of the spectrogram pane.

- 1) For a new record window click here
- 2) To start and stop recording, click here
- 3) Click the spectrogram then on the + button to zoom in to the lower frequencies.
- 4) To change how your spectrogram looks, change the color scheme in the View menu.

SEA OF SOUND



EXTREME ANIMAL COMMUNICATION

Teacher Notes

Before You Start

Time Frame

- Activity: one class period
- Teacher prep time: less than 1 hour

Grade Levels: 10–11

Appropriate for grades 6–12, with extension activities.

Materials Needed

- At least one **computer with speakers** attached. Ideally students would be organized into groups, each with a computer and speakers or headphones.
- **Raven Lite sound analysis software** is available on the *Sea of Sound* DVD. It can also be downloaded for free: seaofsound.org.
- To access the sounds for this exercise, in the **Raven Lite** “File” menu, choose “Open Sound,” then select the lesson’s folder.
- The **bat and whale sound files** for this activity are available on the DVD.
- A **Raven Lite Guide** for each group.
- One **calculator** per group, minimum.
- One **tape measure** per group, long enough to measure the classroom in meters.

Goal

Students should be able to report the frequency limits of human hearing (in Hertz) and name one animal that communicates using ultrasound and one animal that communicates using infrasound. Students should also understand the wavelength equation and be able to use it to calculate the wavelengths of sounds of known frequencies.

Learning Objectives

Students will:

- be able to demonstrate the presence of infrasound or ultrasound in a recording based on sound visualization techniques;
- be able to measure the frequencies of animal calls in the infrasonic and ultrasonic ranges and relate these to human hearing abilities;
- be able to convert frequency measurements into wavelength values and estimate how many wave cycles from a particular animal call would fit into their classroom.

Overview

This activity explores the extremes of animal sound communication by introducing students to animal sounds above and below the frequency thresholds of human hearing. By exploring ultrasonic bat sounds and infrasonic whale sounds using sound visualization software, students prove to themselves that these sounds really exist. They then measure the frequencies of the sounds and convert frequency into wavelength, allowing them to estimate how many wave cycles will fit into their classroom. Blending physics content with biology, this activity also stimulates understanding of why animals might use communication systems radically different from our own.

Prior knowledge

Before beginning this activity, students should have familiarity with the following:

- **Audible:** Sounds that we can hear.
- **Frequency:** The number of peaks that pass by a single point in a given period of time (a rate). The most commonly used unit of sound frequency is Hertz (Hz) measured in cycles per second. For example 1500 Hertz = 1500 cycles per second. This means that 1500 peaks of the wave pass by a single point in one second. 1500 Hertz can also be represented as 1.5 Kilohertz (kHz) because 1000 Hz = 1 kHz.
- **Hertz:** The number of wave cycles per second. For example 1500 Hertz = 1500 cycles per second. 1 Hertz = 1000 Kilohertz.
- **Infrasonic:** Sounds at frequencies too low for the typical human ear to detect. The accepted range for infrasound is 0–20 Hertz.
- **Ultrasonic:** Sounds at frequencies too high for the typical human ear to detect. The accepted upper limit of humans with good hearing is 20,000 Hertz.
- **Wavelength:** The distance between two peaks of a wave.

Background Information:

Animal communication is a powerful theme in the science classroom. Because each species perceives the world through senses tuned specifically for their survival, any investigation of other animals' sensory worlds forces us to consider life from their point of view and to reconsider our understanding of the physical properties of their communication systems. The process of stepping outside human reference points is an important skill in science. One only has to think of the many natural phenomena not immediately obvious to the human senses that have been discovered through scientific inquiry—ultraviolet radiation, black holes, and photosynthesis. The world of bioacoustics holds sensory surprises such as bat and dolphin echolocation above the level of our hearing and whale and elephant vocalizations made in the infrasonic range well below our level of hearing. Sound visualization techniques allow us to detect these hidden surprises.

Teaching Tips

- You may wish to begin this activity with some of the following focus questions:
 - Can animals make sounds that we can't hear?
 - What are the frequency limits of human hearing?
 - What is ultrasound and infrasound?
 - What are the wavelengths of ultrasound and infrasound?
- An effective hook for this activity would be to play an ultrasonic dog whistle for the class and ask if students can hear it. Ask students to brainstorm what they think is happening.
- Another intriguing opener would be to show students the wonderful short video called “Is Laughter Just a Human Thing?” showing the scientist Jaak Panskepp tickling his lab rats and recording their ultrasonic giggles with special equipment. (wnyc.org/shows/radiolab/episodes/2008/02/22)
- Assessment: Students should be able to report the frequency limits of human hearing (in Hertz) and name one animal that communicates using ultrasound and one animal that communicates using infrasound. They should also understand the wavelength equation and be able to use it to calculate the wavelengths of sounds of known frequencies.

Resources

- Wild Music: A traveling exhibition about the sounds and songs of life. This online sound activity allows you to compare the frequency range of sounds you can hear with the frequency range other animals can hear. wildmusic.org/en/aboutsound/mosquito
- Elephant Infrasound: An explanation of elephant infrasound from Cornell University's Elephant Listening Project. <http://goo.gl/BwcZQ>
- In Your Classroom: Sounds of Silence: Infrasound activity on volcanoes and earthquakes. <http://goo.gl/XzgYI>
- Behavior of Sound Waves: Reflection, Refraction, and Diffraction: A physics classroom tutorial that uses the bat example (including the wavelength equation to understand bat echolocation). <http://goo.gl/M4rkp>

National Science Education Standards

UNIFYING CONCEPTS AND PROCESSES: Evidence, Models, and Explanation; Change, Constancy, and Measurement

SCIENCE AS INQUIRY: Understanding About Scientific Inquiry—mathematics is essential in scientific inquiry. Mathematical tools and models guide and improve the posing of questions, gathering data, constructing explanations and communicating results.

PHYSICAL SCIENCE: Interactions of Energy and Matter—waves, including sound and seismic waves, waves on water, and light waves have energy and can transfer energy when they interact with matter.

LIFE SCIENCE: Behavior of Organisms—like other aspects of an organism's biology, behaviors have evolved through natural selection. Behaviors often have an adaptive logic when viewed in terms of evolutionary principles.

SCIENCE AND TECHNOLOGY: Understanding About Science & Technology—science often advances with the introduction of new technologies. Solving technological problems often results in new scientific knowledge. New technologies often extend the current levels of scientific understanding and introduce new areas of research. Creativity, imagination, and a good knowledge base are all required in the work of science and engineering.

Standards-alignment matrices are available on the DVD or at seaofsound.org.

Acknowledgments

By Mya Thompson, Ph.D. at Cornell University under NSF grant DUE # 0532786. Sounds provided by Martyn Stewart of Nature Sound and the Cornell Bioacoustics Research Program. Adapted for *Sea of Sound* by Elizabeth Rice, Colleen McLinn, and Marc Dantzker. Designed by Joanne Avila. Raven Lite was adapted for *Sea of Sound* by Timothy Krein. If reproducing the lesson, please cite the Cornell Lab of Ornithology as the source and provide the URL: seaofsound.org.

This material is based upon work supported by the National Oceanographic Partnership Program (NOPP) and the National Science Foundation (NSF) under award number: OCE-0450717. Any opinions, findings, and conclusions or recommendations expressed in this publication are those of the authors and do not necessarily reflect the views of the NSF or NOPP. © 2011 Cornell University.

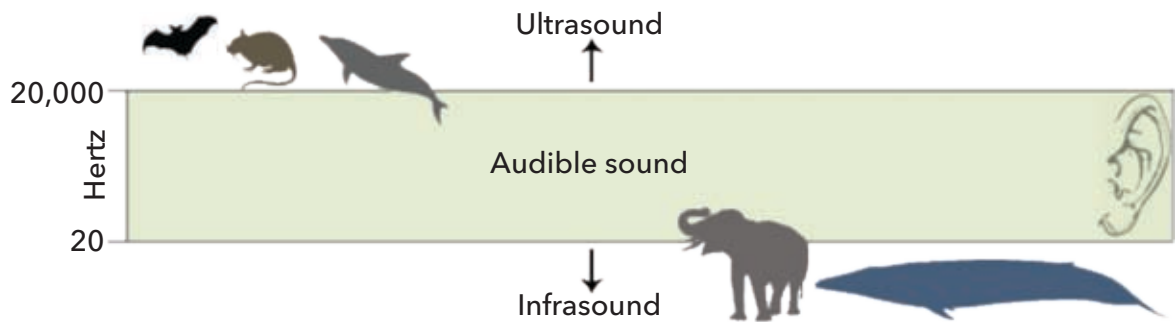


EXTREME ANIMAL COMMUNICATION

Student Handout: Worksheet

Extreme Animal Communication

Did you know that some animals make sounds that we can't hear? Bats, rats, dolphins, elephants, and whales all make sounds that are not audible to us even when we are very close to them. This is not because the sounds are made quietly, but because our ears are not sensitive to very high and very low pitch (frequency) sound. Humans with good hearing can only hear frequencies from about 20 Hertz (wave cycles per second) to about 20,000 Hertz. This may seem impressive, but some animals such as elephants and whales communicate at frequencies below 20 Hz, in what we call the infrasound range. Others, such as bats, rats, and dolphins communicate at frequencies above 20,000 Hertz, in the ultrasonic range.




In this investigation, you will:

- explore recordings of some extreme animal sounds: silver-haired bat calls and blue whale calls;
- use computer software to visualize sound and manipulate playback speed to help you hear frequencies you normally can't detect;
- measure the wavelength of bat and whale sounds and figure out how many bat and whale sound waves will fit inside your classroom.

Materials:

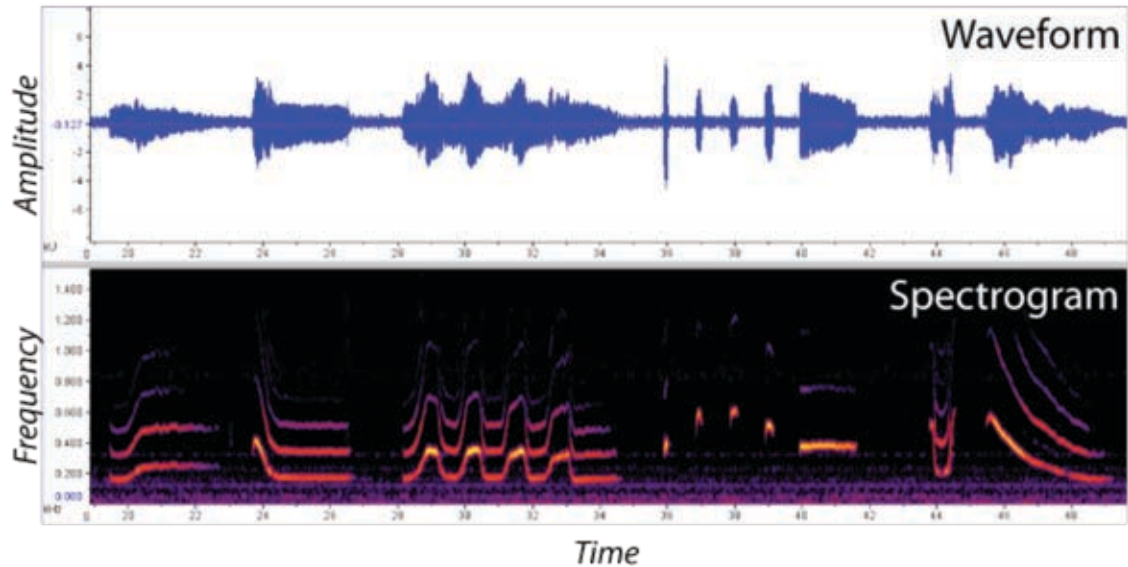
Computer with speakers or headphones and Raven Lite software; sound files of the silver-haired bat and the blue whale, calculator, tape measure (with meters)

Part 1: Infrasound and Ultrasound

Open the program Raven Lite by selecting it from the list of installed programs or clicking on the  icon. Now open the BlueWhale.wav file. You can open sound files by using the **File** menu and selecting **Open Sound Files**. Then select the "Extreme Animal Communication" folder. You will now see two sound graphs. It should look similar to the diagram of the human voice below.

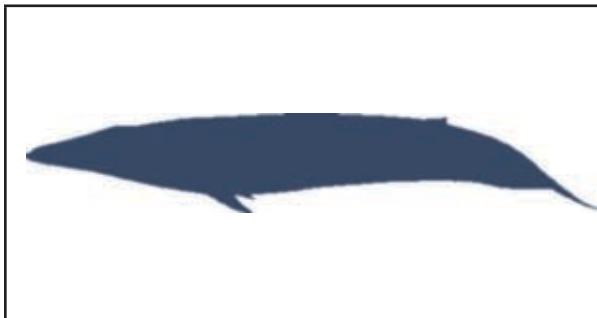
EXTREME ANIMAL COMMUNICATION

Student Handout: Worksheet




The top graph is called a waveform and it shows you the loudness (amplitude) of the sound on the y-axis as time progresses on the x-axis. The bottom graph is a spectrogram showing you the frequency (pitch) of the sound on the y-axis as time progresses on the x-axis. Louder sounds are shown with brighter colors in the spectrogram.

Blue Whale




Blue whales are the largest animals on earth. They are 23-30 meters long (75-100 feet) and can weigh as much as 150 tons. They eat roughly 4 tons of small shrimp-like animals called krill per day. Blue whales were hunted almost to extinction before laws protecting them were passed. Blue whales use sound to communicate long distances underwater. At certain depths and sea conditions, these sounds can be heard by other whales hundreds and perhaps even thousands of kilometers away.

Make sure the sound is working on your computer either through speakers or through headphones and play the blue whale recording by clicking the right-pointing gray triangle on the upper toolbar. You can stop the playback by clicking the gray square .

Can you hear it? _____

Look at the sound graphs. Can you see it on the waveform? _____

Now look at the spectrogram. It is hard to see the sound because it is so low-frequency.

Try zooming in to the low frequencies by repeatedly clicking on the  icon on the upper toolbar until you see ladder-like shapes appearing. What you see are two types of blue whale calls from

EXTREME ANIMAL COMMUNICATION

Student Handout: Worksheet

the Pacific Ocean: first the trill and then the moan. But these sounds were very hard to hear right?

Now try a little trick of the trade. Speed up the recording by typing 10 into the box labeled **rate** on the upper toolbar **Rate: 10**.

Now play it again, can you hear it? _____

Describe what it sounds like. _____

Why can you hear it when you speed up the recording? Because you are tricking your ear into thinking that the sound waves are arriving at your eardrum faster than they do in real life. If sound waves arrive at speeds faster than 20 wave cycles per second (Hertz) then we can hear it.

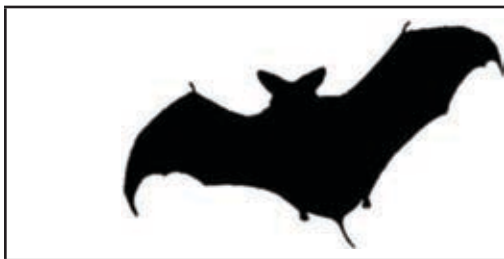
Now, on the spectrogram of the second blue whale call, the moan, drag the horizontal pink line from the bottom of the spectrogram to the point on the y-axis where the lowest rung of the ladder-like shape appears. The frequency of this line is shown to you in blue on the y-axis.

What is the lowest frequency of the blue whale moan? _____

Is this in the infrasonic range? _____

If you were able to hear these sounds without speeding them up, then you have good hearing and/or good speakers or headphones. But this does make sense, because you probably noticed from your analysis that parts of these blue whale sounds (the upper rungs of the ladder) are within the range of human hearing.

Silver-haired bat



Silver-haired bats live all over North America, even in your backyard. They can live up to 12 years and are about 30 cm long (12 inches). They feed at night on small insects, especially moths. They detect their prey in the dark using echolocation—sending out high-frequency sounds and then listening for the sound patterns that bounce back at them as it hits their prey.

Now open the silver-haired bat recording (SilverHairedBat.wav) and play it by clicking the right-pointing gray triangle on the upper toolbar. You can stop the playback by clicking the gray square .

Can you hear it? _____

Look at the sound graphs. Can you see it on the waveform? _____

Can you see it on the spectrogram? _____

EXTREME ANIMAL COMMUNICATION

Student Handout: Worksheet

Now, to translate these sounds into our hearing range, slow down the recording by 10 times by typing .1 into the box labeled **rate** on the upper toolbar **Rate: .1**.

Now play it again, can you hear it? _____

Describe what it sounds like. _____

Why can you hear the chirp-like sounds when you slow down the bat recording? The wave cycles of the bat sounds were arriving at your ear too quickly for you to sense them. You have to trick the ear by slowing the waves to less than 20,000 cycles per second. Small electronic "bat detectors" automatically slow bat sounds so that people can find them at night.

Now, on the spectrogram of the bat calls, drag the horizontal pink line from the bottom of the spectrogram to the point on the y-axis where the highest frequency in a bat call appears. The frequency of this line is shown to you in blue on the y-axis.

What is the highest frequency of the silver-haired bat call? _____
(Watch the scale as it changes to Kilohertz (kHz) because we are at high-frequencies 1Hz = 1000 kHz)

Is this in the ultrasonic range? _____

Did you know some adults can't hear very high frequency cell phone ring tones? This is because some adults lose their high-frequency hearing sensitivity with age. Some shopkeepers also use high frequency sounds to deter loitering teenagers!

Part 2: Wavelengths of Extreme Animal Sounds

$$\lambda = v/f$$

λ = wavelength (meters/cycle)

v = speed of sound (meters/second or m/s)

f = frequency (cycles/second = Hertz)

Speed of sound:	Air	Seawater
Range	325-355 m/s	1400-1700 m/s
Average	340 m/s	1550 m/s

Calculate the wavelength of the lowest frequency in the blue whale call you measured using the formula above. _____

How many meters is the longest wall of the classroom? _____

Roughly how many of these sound waves could fit into your classroom? (if it were underwater)

EXTREME ANIMAL COMMUNICATION

Student Handout: Worksheet

Calculate the wavelength of the highest frequency in the bat call using the formula above.

Roughly how many of these sound waves could fit into your classroom? _____

Vocabulary:

Audible: Sounds that we can hear.

Frequency: The number of peaks that pass by a single point in a given period of time (a rate). The most commonly used unit of sound frequency is Hertz (Hz) measured in cycles per second. For example, 1500 Hertz = 1500 cycles per second. This means that 1500 peaks of the wave pass by a single point in one second. 1500 Hertz can also be represented as 1.5 Kilohertz (kHz) because $1000 \text{ Hz} = 1 \text{ kHz}$.

Hertz: The number of wave cycles per second. For example, 1500 Hertz = 1500 cycles per second. $1 \text{ Hertz} = 1000 \text{ Kilohertz}$.

Infrasonic: Sounds at frequencies too low for the typical human ear to detect. The accepted range for infrasound is 0-20 Hertz.

Ultrasonic: Sounds at frequencies too high for the typical human ear to detect. The accepted upper limit of humans with good hearing is 20,000 Hertz.

Wavelength: The distance between two peaks of a wave.

EXTREME ANIMAL COMMUNICATION

Student Handout: Raven Lite Guide

Full documentation at www.birds.cornell.edu/brp/raven/raven/RavenDocumentation.html

At-a-glance guide to Raven Lite

Menu (Raven Lite 1.0 File Edit View Window Help)

Toolbar (Icons for file operations, playback, zoom, and analysis)

Sound (Audio file: Sound 11: Right Whales.wav)

Waveform (Amplitude view showing signal over time)

Spectrogram (Frequency view showing spectral content over time)

Playback Controls (Play, Stop, Speed)

Spectrogram Controls (Brightness, Contrast, Detail)

Zoom options (Zoom in, Zoom out, Reset)

Measurement bars (Drag purple lines to desired point in time, frequency or amplitude and read result on the axis (in blue))

Time (Horizontal axis for both views)

Loudness (Amplitude) (Vertical axis for Waveform view, scale 0 to 30)

Pitch (Frequency) (Vertical axis for Spectrogram view, scale 0.000 to 10 kHz)

Time (Horizontal axis for Spectrogram view, scale 5 to 30 seconds)

Time (Bottom status bar: Time: 16.482 S Minimum: -2427 Maximum: 2318)

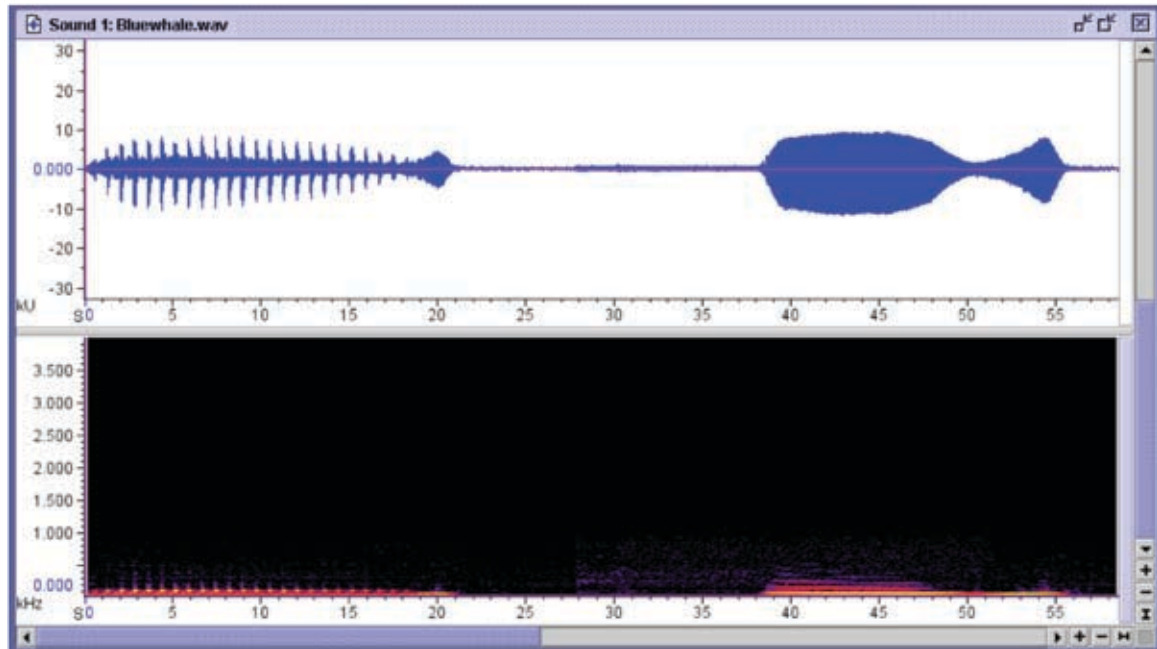
EXTREME ANIMAL COMMUNICATION

Worksheet: Answers

Part 1: Infrasound and Ultrasound


Blue whale:

The students should be seeing a screen that looks like this:



Can you hear it? Maybe barely, a low throbbing

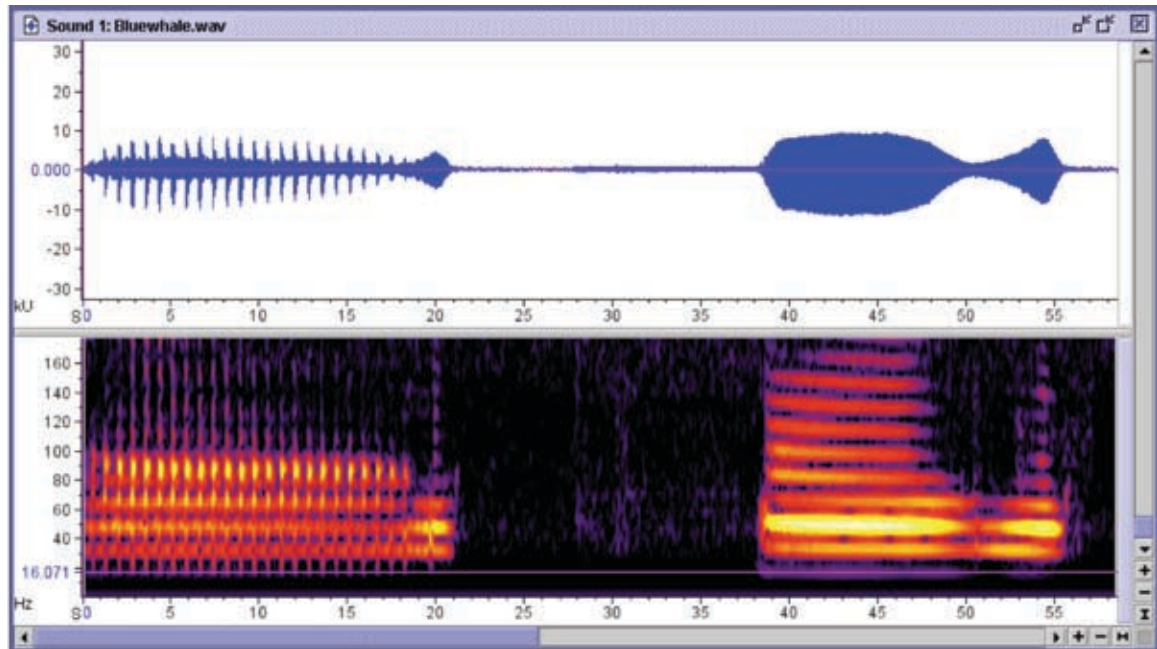
Look at the sound graphs. Can you see it on the waveform? Yes

Now look at the spectrogram. It is hard to see the sound because it is so low-frequency. Try zooming in to the low frequencies by repeatedly clicking on the  icon on the upper toolbar until you see ladder-like shapes appearing. What you see are two types of blue whale calls from the Pacific Ocean: first the trill and then the moan.

EXTREME ANIMAL COMMUNICATION

Worksheet: Answers

The students should be seeing a screen that looks like this after zooming in:



Now try a little trick of the trade. Speed up the recording by typing 10 into the box labeled **rate** on the upper toolbar **Rate: 10**.

Now play it again, can you hear it? Yes

Describe what it sounds like.

The first sounds a bit like a mouth harp and the second sounds a bit like a foghorn.

Now, on the spectrogram of the second blue whale call, the moan, drag the horizontal pink line from the bottom of the spectrogram to the point on the y-axis where the lowest rung of the ladder-like shape appears. The frequency of this line is shown to you in blue on the y-axis.

What is the lowest frequency of the blue whale moan?

~16 Hz, the pale purple line is lowest frequency (see above diagram)

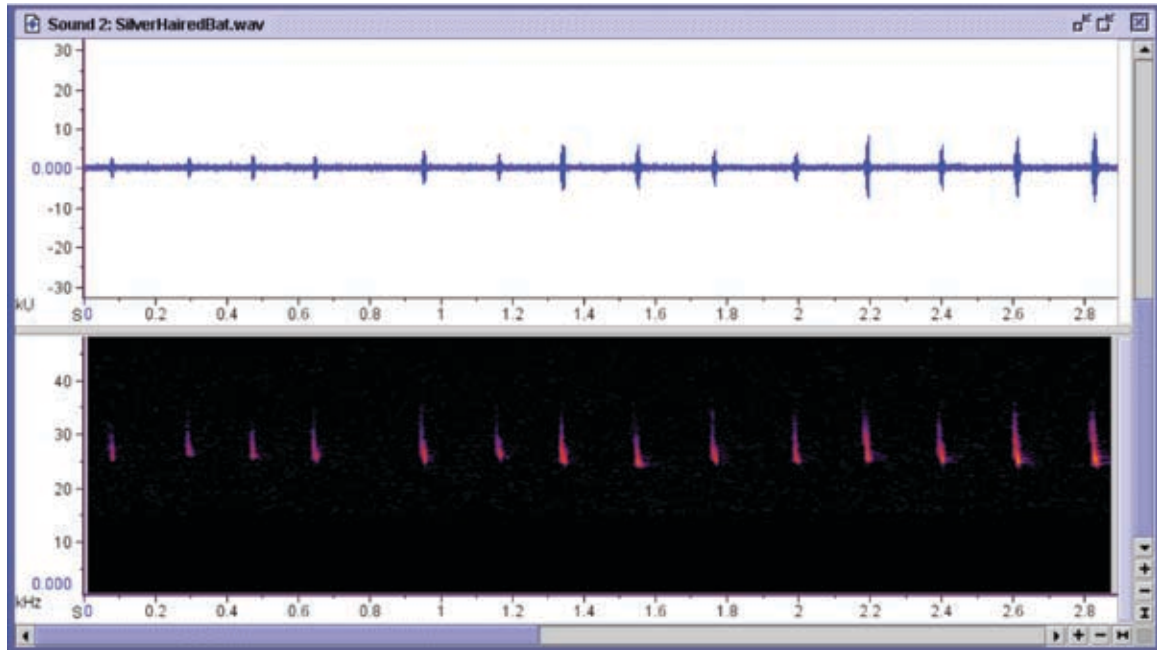
Is this in the infrasonic range? Yes!

EXTREME ANIMAL COMMUNICATION

Worksheet: Answers

Silver-haired bat

The students should be seeing a screen that looks like this:



Can you hear it? No

Look at the sound graphs. Can you see it on the waveform? Yes

Can you see it on the spectrogram? Yes

Now to translate these sounds into our hearing range, slow down the recording by 10 times by typing .1 into the box labeled **rate** on the upper toolbar **Rate:** .

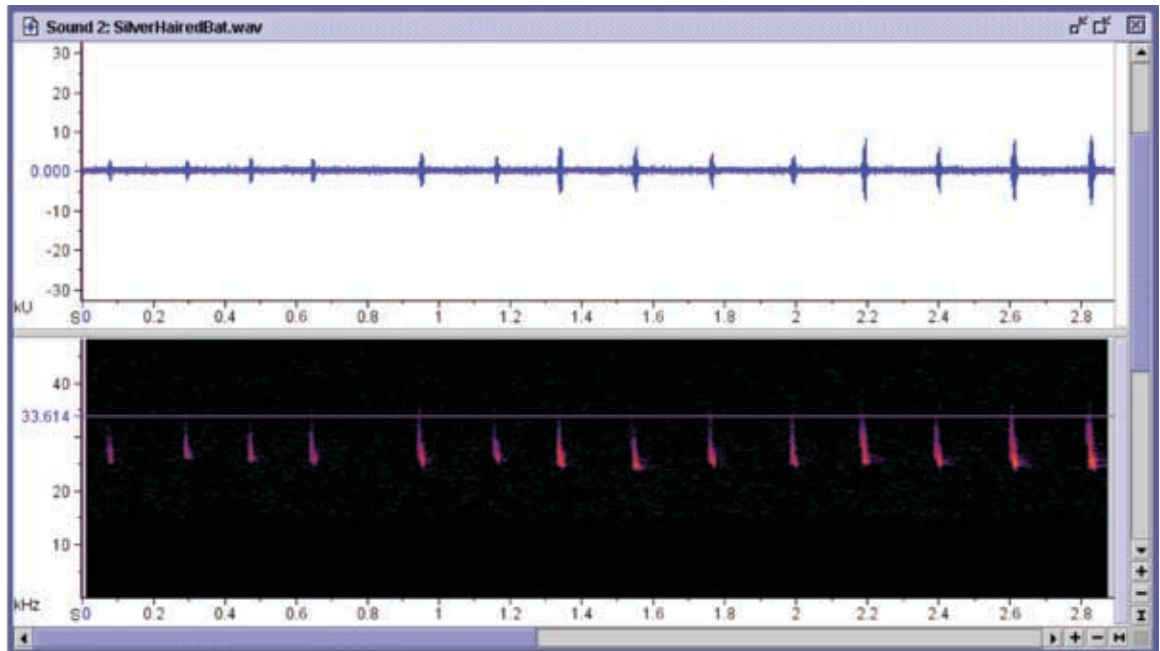
Now play it again, can you hear it? Yes

Describe in words what it sounds like: It sounds a bit like a bird chirping.

EXTREME ANIMAL COMMUNICATION

Worksheet: Answers

Now, on the spectrogram of the bat calls, drag the horizontal pink line from the bottom of the spectrogram to the point on the y-axis where the highest frequency in a bat call appears. The frequency of this line is shown to you in blue on the y-axis.



What is the highest frequency of the Sliver-haired bat call?

~33 Kilohertz = 33,000 Hz (See above diagram, watch the scale as it changes to Kilohertz when viewing high-frequency sound!)

Is this in the ultrasonic range? Yes!

EXTREME ANIMAL COMMUNICATION

Worksheet: Answers

Part 2: Wavelengths of Extreme Animal Sounds

$$\lambda = v/f$$

λ = wavelength (meters/cycle)

v = speed of sound (meters/second or m/s)

f = frequency (cycles/second = Hertz)

Speed of sound:	Air	Seawater
Range	325-355 m/s	1400-1700 m/s
Average	340 m/s	1550 m/s

Calculate the wavelength of the lowest frequency in the blue whale call you measured using the formula above.

$$1550 \text{ meters/second} / 16 \text{ cycles/second} = 97 \text{ meters/cycle}$$

How many meters is the longest wall of the classroom?

Let's say the room is 6m (about 20 ft).

Roughly how many of these sound waves could fit into your classroom (if it were underwater)?

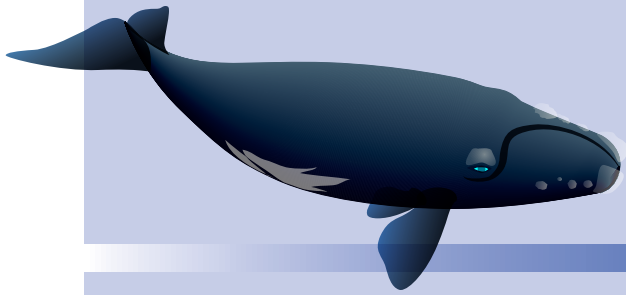
$$\text{A very tiny fraction of one wave cycle! } 6 \text{ m} / 97 \text{ m} = 0.0$$

Calculate the wavelength of the highest frequency in the bat call using the formula above.

$$340 \text{ meters/second} / 33,000 \text{ cycles/second} = 0.01 \text{ meters/cycle!}$$

Roughly how many of these sound waves could fit into your classroom?

$$6 \text{ m} / 0.01 \text{ m} = 600 \text{ wave cycles, wow!}$$



SEEING SOUND

Teacher Notes

Before You Start

Time Frame

- Activity: 60 minutes. Each of the three parts of the activity will take approximately 20 minutes.
- Teacher prep time: less than 1 hour

Grade Level: 10–11

Appropriate for grades 6–12, with extension activities.

Materials Needed

- At least one **computer with microphone attached**. Ideally students would be organized into groups, each with a computer and microphone.
- **Raven Lite sound analysis software** is available on the *Sea of Sound* DVD. It can also be downloaded for free at seaofsound.org.
- To access the sounds for this exercise, in the **Raven Lite** “File” Menu, choose “Open Sound,” then select the lesson’s folder.
- The **Sound Files** for this activity are available on the DVD.
- A **Raven Lite Guide** for each group
- A **Raven Lite Recording Guide** for each group
- One **calculator** per group, minimum
- One **tape measure** per group, long enough to measure the classroom in meters

Goals

Students will understand the differences between high and low-frequency sounds. Students will be able to draw simple pictures of how a high-frequency sound differs from a low-frequency sound both in waveform and spectrogram formats.

Learning Objectives

Students will:

- be able to predict and describe what a time-amplitude representation of a sound (waveform) should look like;
- be able to describe in general terms a time-frequency representation of a sound (spectrogram);
- be able to predict the dominant frequency of a sound by making measurements on a waveform;
- be able to predict whether a sound contains multiple frequencies by exploring the waveform.

Overview

This lab is designed to give students a greater understanding of sound waves and wave mechanics by introducing visual methods for interpreting sound and using these graphical displays to explore their own voices as well as sound from the natural world.

Prior knowledge

Before beginning this activity, students should have familiarity with the following:

- **Amplitude:** The pressure of the medium (air, water, solid) at the peak of a sound wave. The higher the pressure, the louder a sound is to our ears.
- **Cycle:** At a fixed point, one wave cycle is one round of high pressure followed by low pressure. On a waveform, the cycle is the portion of the wave between two adjacent peaks.
- **Frequency:** The number of peaks that pass by a single point in a given period of time (a rate). The most

commonly used unit of sound frequency is Hertz (Hz) measured in cycles per second. For example 1,500 Hertz = 1,500 cycles per second. This means that 1,500 peaks of the wave pass by a single point in one second. 1,500 Hertz can also be represented as 1.5 Kilohertz (kHz) because 1,000 Hz = 1 kHz.

- **Hertz:** The number of wave cycles per second. For example 1,500 Hertz = 1,500 cycles per second.
- **Longitudinal wave:** A sound wave is longitudinal because the individual molecules vibrate in the same direction as the mechanical wave moves.
- **Mechanical wave:** A mechanical wave results from the back and forth vibration of molecules in the medium through which the wave is moving. As a sound source vibrates, it compresses molecules in the surrounding medium (air, water, or solid), resulting in a high-pressure zone. This compression travels forward as molecules collide with one another leaving behind a low-pressure zone. The molecules themselves only move enough to collide with adjacent molecules but the wave can travel long distances. Mechanical waves like sound cannot travel in a vacuum because there are no molecules to collide with one another and send the wave forward.
- **Period:** The amount of time it takes to complete one wave cycle. When analyzing a waveform the period is the amount of time between two peaks.
- **Spectrogram:** A representation of a sound wave with time on the x-axis, frequency on the y-axis, and amplitude as the color scale. Any waveform can be mathematically broken down into individual frequencies and displayed in a spectrogram.
- **Waveform:** A representation of a sound wave with time on the x-axis and amplitude on the y-axis. Pressure increases and decreases at the microphone as sound waves pass by. These changes are turned into an electrical signal and processed by a computer to show the waveform.

Background Information:

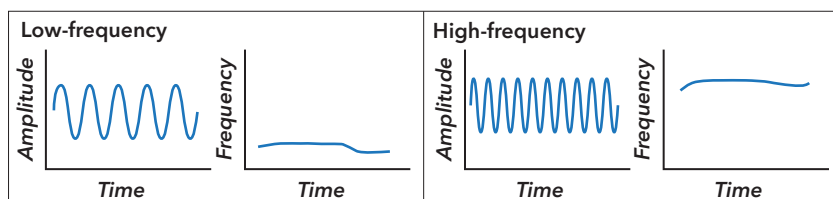
Scientists studying animal sounds have found that the intersection of biology and physics has produced a diversity of fascinating sound patterns. This project is designed to give students a little sample of that diversity and help them enhance their understanding of sound waves using visual representations of natural sound.

Students will first experiment with their own voices, exploring two different visual representations of the sounds—waveforms and a time-frequency representation or spectrogram. Then they will listen to a number of bird songs and try to predict what the time-frequency representation of those sounds would look like (much like writing out music in musical notation). Students will then examine and measure those sounds more closely, using waveforms and spectrograms.

Teaching Tips

Assessment: Students will have grasped the main message of the activity if they can draw simple pictures of how a high-frequency sound differs from a low-frequency sound both in waveform and spectrogram formats. Rough sketches of what you should expect for correct answers are shown.

Spectrogram and waveform



For deeper understanding of the concept of a mechanical wave and how sounds travel in water and air, consider using this lesson with the Speed of Sound lesson that follows in this document.

Resources

- Explore more animal sounds by visiting the world's largest collection of animal sounds at the Cornell Lab of Ornithology's Macaulay Library. macaulaylibrary.org
- Learn more about the Bioacoustics Research Program at the Cornell Lab of Ornithology. birds.cornell.edu/brp
- Raven Lite software guides are available at RavenSoundSoftware.com.

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Standards-alignment matrices are available on the DVD or at seaofsound.org.

Acknowledgments

By Mya Thompson, Ph.D. and Jesse Ellis, Ph.D. at Cornell University under NSF grants DGE # 0231913, DGE # 9979516, and DUE # 0532786. Adapted for *Sea of Sound* by Elizabeth Rice, Colleen McLinn, and Marc Dantzker. Designed by Joanne Avila. Sounds provided by the Macaulay Library, Cornell Lab of Ornithology. Raven Lite was adapted for *Sea of Sound* by Timothy Krein. If reproducing the lesson, please cite Cornell Lab of Ornithology as the source and provide the following URL: seaofsound.org.

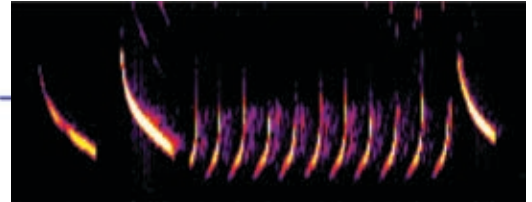
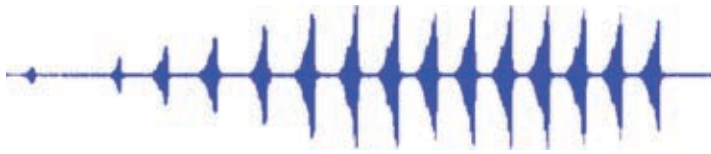
This material is based upon work supported by the National Oceanographic Partnership Program (NOPP) and the National Science Foundation (NSF) under award number: OCE-0450717. Any opinions, findings, and conclusions or recommendations expressed in this publication are those of the authors and do not necessarily reflect the views of the NSF or NOPP. © 2011 Cornell University.



SEEING SOUND

Student Handout: Worksheet

Seeing Sound



Now you will be looking at sound rather than listening to it. You may be wondering how you can “see” sound and why you would want to. Graphing sound waves can make it easier to understand what we hear because it helps us measure sound in very precise ways. Sound graphs can also be very beautiful, reflecting the complexity and uniqueness of the sound itself.

A sound is a mechanical wave that travels through air, water, or solid material but cannot travel in a vacuum. For example, when a bird sings, it disturbs the air around it by compressing air molecules in a small area around its head. As the air molecules collide in that high-pressure zone, they send the energy of collision forward to other air molecules farther from the bird’s head, leaving a low-pressure zone behind it. This forward momentum creates a new high-pressure zone, which then travels outward again as molecules continue to collide. If we stand in one place, these fronts of high and low pressure travel past us, moving our eardrum in and out and allowing us to hear sound. Sounds with higher pressure are louder to our ears (higher in amplitude). When high-pressure fronts are produced more rapidly the sound is higher in pitch (frequency) to our ears. Sound is referred to more specifically as a longitudinal wave because the individual molecules vibrate parallel to the direction in which the sound wave moves.



Graphing sound waves can often make it easier for us to understand them—but how do we turn pressure into something we can see?

In this investigation, you will:

- explore how your voice looks on a sound graph;
- predict what bird song looks like on a sound graph and compare your results with the real thing;
- learn to measure sound waves using computer software.






Materials:

Computer with a microphone and Raven Lite software, your voice, sound files of bird calls, calculator

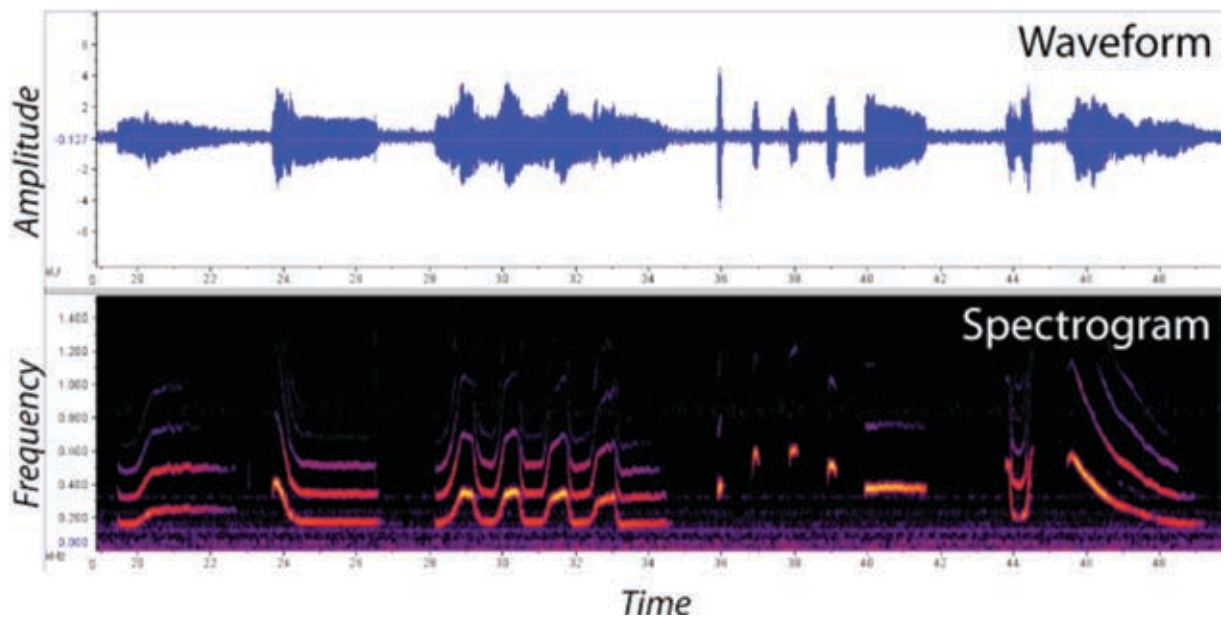
SEEING SOUND

Student Handout: Worksheet

Part 1: See Your Own Sound

Let's begin by making pictures of your own voice on a computer screen. Open the Raven Lite program. On the top toolbar click on the picture of the microphone  to start recording, and click on the green triangle on the bottom left of the screen  **Not recording.** **Once you are recording, watch both graphs on your screen as you talk, sing, whistle, hum, or imitate an animal.** If you are not seeing the blue line in the upper panel jump around as you talk, you may need to change the sound settings on your computer—ask your teacher how to do this. When you want to pause the recording, click the green square on the bottom right of the screen  **Recording to memory...**. Once you have paused the recording, you can play back your voice by clicking the gray triangle on the upper toolbar and stop it by clicking the gray square  .

Explore the limits of your voice. Make all different kinds of noise. Are you getting an idea of how the sound is graphed in the two different displays? The top display is called the waveform and the bottom display is called the spectrogram. *Underlined words are defined in the vocabulary guide at the end of this handout.*



There are three main properties of sound being displayed on these graphs, 1) time, 2) amplitude, and 3) frequency. Let's explore.

(Draw or write your answers, choose the method that makes most sense to you).

SEEING SOUND

Student Handout: Worksheet

1. TIME:

Hum for about 1 second, pause, then hum for about 5 seconds while using Raven Lite to record on your computer. Pause your recording.

How does the waveform change when you lengthen the time you hum?

How does the spectrogram change when you when you lengthen the time you hum?

2. AMPLITUDE (LOUDNESS):

Whisper the word “hello” then speak the word “hello” loudly. Pause your recording.

How does the waveform change as your voice gets louder?

How does the spectrogram change as your voice gets louder?

3. FREQUENCY (PITCH):

Hum the highest-pitched sound that you can, followed by the lowest-pitched sound that you can while trying to keep a constant amplitude. Pause your recording.

How does waveform change when you compare the high-pitched sound to the low-pitched sound?

SEEING SOUND

Student Handout: Worksheet

How does the spectrogram change when you compare the high-pitched sound to the low-pitched sound?


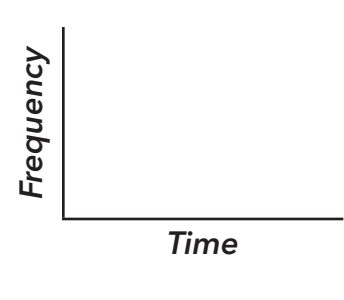
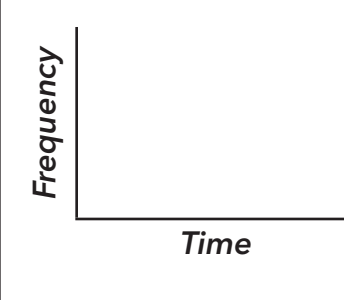
Extra challenge:

Get two friends and try to use the sound of your voices to make a square on the spectrogram. You'll have to think very carefully about how to do it. Can two of you make a triangle? Describe how you did it.

Part 2: See Bird Sound

Now that you have good idea of how sound is displayed graphically, challenge yourself to predict what the spectrograms of a few different bird calls would look like.

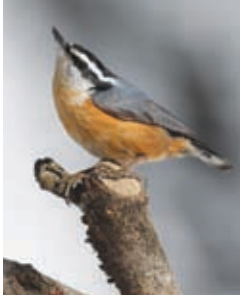


- Without using the Raven software to make sound graphs, click the sound files listed below and listen carefully to each. As you listen, sketch a spectrogram predicting what you think the sound file will look like as a spectrogram on the computer.
 - Eastern Screech-Owl: These birds can be heard calling at all times of year in the eastern United States and southeastern Canada.

	Prediction	Actual
 <small>TERRY SEARS</small>		




SEEING SOUND

Student Handout: Worksheet

- b. Red-breasted Nuthatch: These birds are found in pine forests throughout western and northern North America.

	Prediction	Actual
 <p style="text-align: right; font-size: small;">CHRISTINE HAINES</p>	<p style="text-align: center;">Frequency</p>  <p style="text-align: center;">Time</p>	<p style="text-align: center;">Frequency</p>  <p style="text-align: center;">Time</p>

- c. Common Nightingale: Male nightingales sing long, complicated songs to attract mates. They are found in parts of Europe and Africa.

	Prediction	Actual
 <p style="text-align: right; font-size: small;">SERGEY YELISEEV</p>	<p style="text-align: center;">Frequency</p>  <p style="text-align: center;">Time</p>	<p style="text-align: center;">Frequency</p>  <p style="text-align: center;">Time</p>

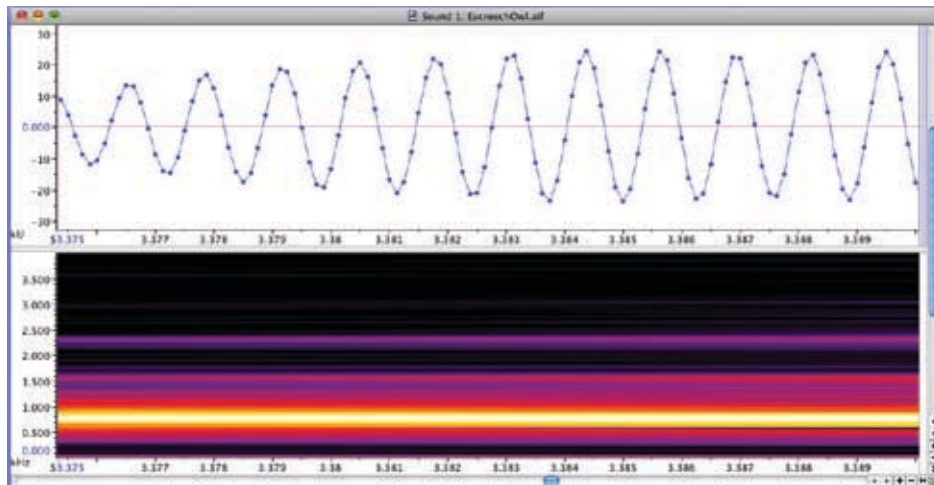
2. Open each of the sounds in the Raven Lite software and look at the actual spectrograms. Draw each in the space provided next to your predictions. To open sounds in Raven Lite simply drag them to the light blue Raven Lite window. How did you do? Was it hard to predict what the spectrogram would look like? Did you even try with the nightingale?


SEEING SOUND

Student Handout: Worksheet

Part 3: Measuring Bird Sound

You are ready to link the sound graphs to the physics of sound by making some measurements on waveforms and spectrograms of the birdcalls you just listened to.



First open the Eastern Screech-Owl sound in Raven Lite and look at the waveform. (Underlined terms explained in vocabulary guide at the end of the document.) Can you see how the owl makes a series of sound bursts? Now, zoom in by clicking the  button on the toolbar until you see individual waves and blue dots appear on the waveform. Measure the time between two consecutive peaks of the waveform at a point in the sound when the peaks are most obvious to you and **record it in the Sample 1 data table below**—this is the period of one wave cycle (see diagram above).

Because Raven Lite does not give all the significant digits you need, estimate the start and end time as best you can—it will be just a tiny fraction of a second. Then measure the period of the screech-owl call in another part of the sound by scrolling forward using the bottom scroll bar and **record it in the data table for Sample 2.**

Now you will transform your period measurement into a prediction of the frequency (pitch) of the screech-owl call. Frequency is a rate measured in Hertz. How can you translate a measurement of period into Hertz?

If your period was exactly one second, then the frequency would be 1 Hertz (1 Hertz = 1 cycle / 1 second), so all you need to do is **use the equation below to fill in the predicted frequency box in your data table:**

_____ Hertz = 1 cycle / _____ seconds (duration of <u>period</u>)
--

SEEING SOUND

Student Handout: Worksheet

Data Table:

Sample	Period (seconds)	Predicted frequency from waveform (1 cycle/x seconds = Hertz)
	2.1194 - 2.1180 = 0.0014	1/0.0014 = 714
		Measured frequency from spectrogram (Hertz)
		731

Eastern Screech-Owl	Period (seconds)	Predicted frequency from waveform (1 cycle/x seconds = Hertz)
		Measured frequency from spectrogram (Hertz)

Now, let's take a look at the screech-owl spectrogram. Use the cursor to measure the frequency of the call and **record it in the data table for both samples**. Frequency in Hertz appears on the bottom left of the screen and looks like this: **Time: 1.000 S Frequency: 1709 Hz Power: 46.6 dB**. Note: Raven Lite displays frequency along the y-axis in Kilohertz (kHz), 1 kHz = 1,000 Hz.

How did your predicted frequency from the waveform compare to your measured frequency on the spectrogram? If you are within 30 Hertz you are doing a great job. You have completed the first step of what the computer is doing when it transforms waveforms into spectrograms. In practice, biologists use spectrograms more often than waveforms because frequency changes are obvious at a glance and can be readily measured.

Now open the Red-breasted Nuthatch call in Raven Lite and try to make the same period measurement on the waveform. You will notice as you zoom in that this waveform is more complicated than the screech-owl's making it hard to choose where to measure the period. Try to answer the questions below as best you can.

1. Do the periods remain constant throughout the waveform? _____
2. Now take a look at the spectrogram. What is the major difference between the nuthatch spectrogram and the screech-owl spectrogram? _____

The bands you see on the spectrogram are called harmonics. Look familiar? Our voices also contain harmonics, so you probably noticed them earlier when you were getting to know spectrograms. Many natural sounds contain harmonics, including musical instruments, such as guitars.

SEEING SOUND

Student Handout: Worksheet

3. What is the frequency of the lowest frequency band? _____
4. What is the frequency of the next band above the lowest? _____
5. Subtract the #3 from #4. _____

The answers to 3) and 5) should match because the spacing between harmonics is the same as the lowest frequency of the call. The regular spacing of harmonics is a result of natural vibrations of the vocal cords.

You don't need to measure the nightingale song but you can explore the different notes in his song (this is a male's song) by zooming in on each note and comparing the waveform and spectrogram. See if higher-pitched notes have shorter periods than lower-pitched notes.

SEEING SOUND

Student Handout: Worksheet

Vocabulary guide:

Amplitude: The pressure of the medium (air, water, solid) at the peak of a sound wave. The higher the pressure, the louder a sound is to our ears.

Cycle: At a fixed point, one wave cycle is one round of high pressure followed by low pressure. On a waveform, the cycle is the portion of the wave between two adjacent peaks.

Frequency: The number of peaks that pass by a single point in a given period of time (a rate). The most commonly used unit of sound frequency is Hertz (Hz) measured in cycles per second. For example 1,500 Hertz = 1,500 cycles per second. This means that 1,500 peaks of the wave pass by a single point in one second. 1,500 Hertz can also be represented as 1.5 Kilohertz (kHz) because 1,000 Hz = 1 kHz.

Hertz: The number of wave cycles per second. For example 1,500 Hertz = 1,500 cycles per second.

Longitudinal wave: A sound wave is longitudinal because the individual molecules vibrate parallel to the direction in which the mechanical wave moves.

Mechanical wave: A mechanical wave results from a back and forth vibration of molecules in the medium through which the wave is moving. As sound source vibrates, it compresses molecules in the surrounding medium (air, water, or solid), resulting in a high-pressure zone. This compression travels forward as molecules collide with one another leaving behind a low-pressure zone. The molecules themselves only move enough to collide with adjacent molecules but the wave can travel long distances. Mechanical waves like sound cannot travel in a vacuum because there are no molecules to collide with one another and send the wave forward.

Period: The amount of time it takes to complete one wave cycle. When analyzing a waveform, the period is the amount of time between two peaks.

Spectrogram: A representation of a sound wave with time on the x-axis, frequency on the y-axis and amplitude as the color scale. Any waveform can be mathematically broken down into individual frequencies and displayed in a spectrogram.

Waveform: A representation of a sound wave with time on the x-axis and amplitude on the y-axis. Pressure increases and decreases at the microphone as sound waves pass by. These changes are turned into an electric signal and processed by your computer to show the waveform.

SEEING SOUND

Student Handout: Raven Lite Guide

Full documentation at www.birds.cornell.edu/brp/raven/RavenDocumentation.html

At-a-glance guide to Raven Lite

Menu (Raven Lite 1.0 File Edit View Window Help)

Toolbar (Icons for file operations, playback, zoom, and measurement)

Sound (Main audio analysis area)

Waveform (Top view of the audio signal)

Spectrogram (Bottom view of the audio signal's frequency content)

Measurement bars (Drag the purple lines to desired point in time, frequency or amplitude and read result on the axis (in blue))

Zoom options (Zoom in, zoom out, and reset buttons)

Playback Controls (Play, Stop, Speed)

Spectrogram Controls (Brightness, Contrast, Detail)

Waveform view (Amplitude vs. Time)

Spectrogram view (Frequency vs. Time)

Loudness (Amplitude) (Kilo Units - an uncalibrated unit of sound pressure)

Pitch (Frequency) (Kilohertz - 1000 cycles/second)

Time (Seconds)

Time: 16.482 S Minimum: -2427 Maximum: 2318

SEEING SOUND

Student Handout: Raven Lite Recording Guide



How to record



Make sure your computer has a microphone plugged in and working by choosing one of the microphone icons from the toolbar and then beginning a recording (see below). If you do not see changes in the upper blue graph as you speak, check the audio options on your computer.

The screenshot shows the Raven Lite 1.0 software window. The top menu bar includes 'Raven Lite 1.0', 'File', 'Edit', 'View', 'Window', and 'Help'. Below the menu is a toolbar with various icons for recording, editing, and playback. The main window is divided into two sections: 'Recorder 4: Built-in Microphone'. The top section is labeled 'Waveform' and shows a blue audio waveform. The bottom section is labeled 'Spectrogram' and shows a frequency spectrum with a color scale from 0.000 to 36.6 kHz. The x-axis for both is labeled 'Time' and ranges from -5 to 36.6. The y-axis for the spectrogram is labeled 'kHz' and ranges from 0.000 to 20. A status bar at the bottom right says 'Not recording.'.

1) For a new record window click here

2) To start and stop recording, click here

3) Click the spectrogram then on the + button to zoom in to the lower frequencies.

4) To change how your spectrogram looks, change the color scheme in the View menu.

SEEING SOUND

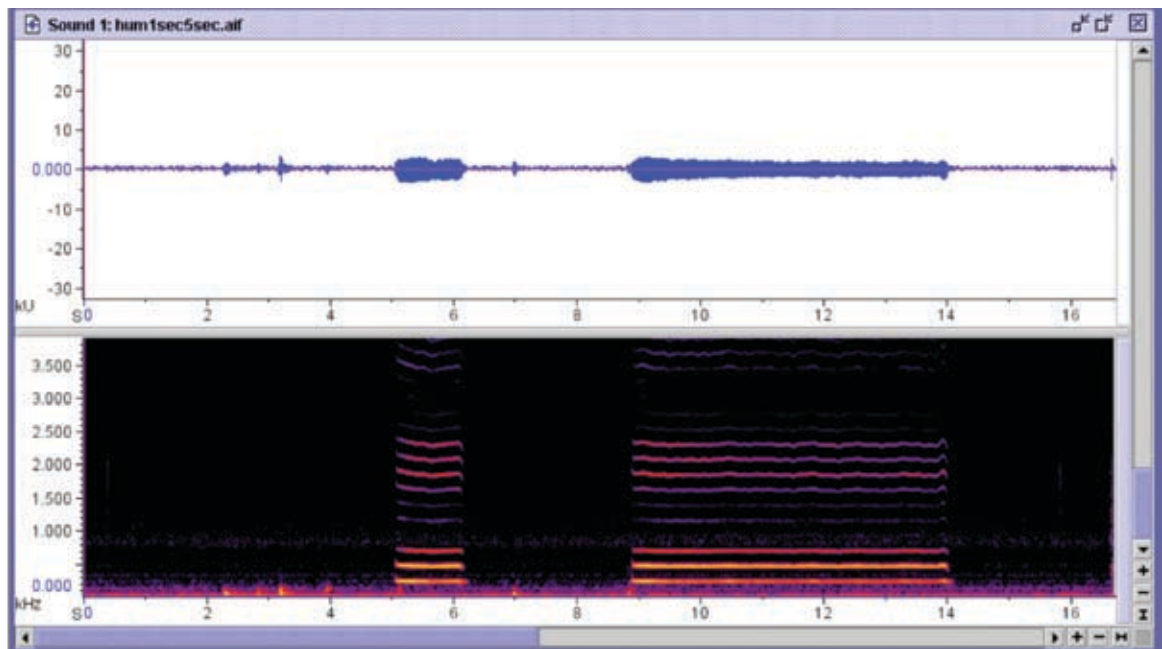
Worksheet: Answers

Part 1: See Your Own Sound

A. TIME:

Hum for one second, be quiet for a few seconds, and then hum for five more seconds. Pause your recording.

The students should be seeing a screen that looks like this:



How does the waveform change when you lengthen the time you hum?

The sound burst takes up more of the x-axis.

How does the spectrogram change when you lengthen the time you hum?

The sound burst takes up more of the x-axis.

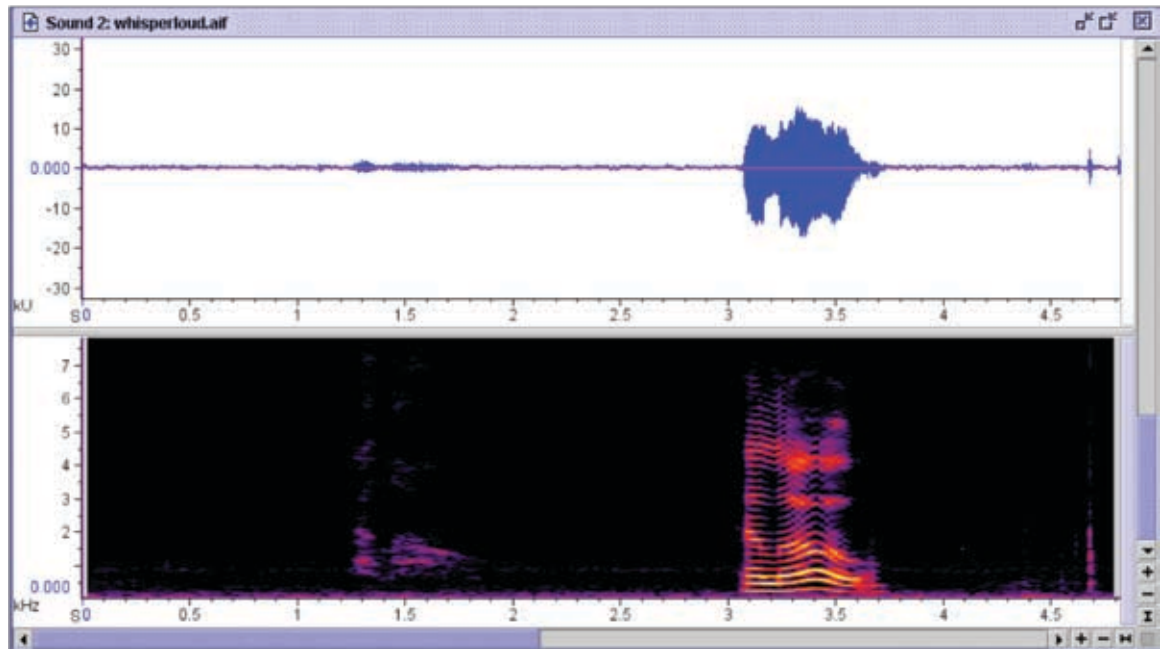
SEEING SOUND

Worksheet: Answers

B. AMPLITUDE (LOUDNESS):

Whisper the word "hello" then speak the word "hello" loudly. Pause your recording.

The students should be seeing a screen that looks like this:



How does the waveform change as your voice gets louder?

The sound burst takes up more of the y-axis.

How does the spectrogram change as your voice gets louder?

The sound burst is brighter (more yellow) on the screen.

C. FREQUENCY (PITCH):

Hum the highest-pitched sound that you can, followed by the lowest-pitched sound that you can while trying to keep a constant amplitude. Pause your recording.

How does waveform change when you compare the high-pitched sound to the low-pitched sound?

For the purposes of this question, you hope the students find no difference between high and low-frequency sounds on the waveform. If the amplitude is really kept constant, the only way you can tell the pitch from the waveform is to zoom in time. That is why spectrograms are so helpful—they display frequency.

SEEING SOUND

Worksheet: Answers

How does the spectrogram change when you compare the high-pitched sound to the low-pitched sound?

The high-frequency sound is higher on the y-axis than the low-frequency sound.

Extra challenge:


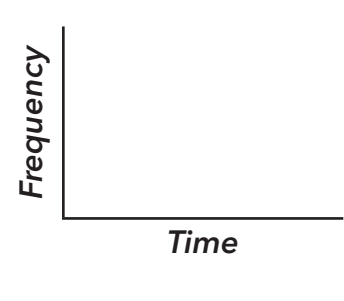
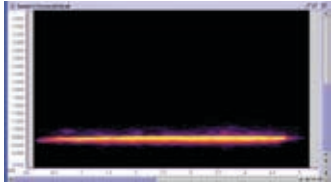
Get two friends and try to use the sound of your voices to make a square on the spectrogram. You'll have to think very carefully about how to do it. Can two of you make a triangle? Describe how you did it.

If one student bangs a book on the table as two others hum a high and a low-pitched note, then the first student bangs again, a group can create something like a square. A triangle can be made by two students starting to hum at the same frequency. One student remains at that frequency while another sweeps up to higher frequencies and back down again to meet the constant hummer.

Part 2: See Bird Sound

Now that you have good idea of how sound is displayed graphically, challenge yourself to predict what the spectrograms of a few different bird calls would look like.

- Without using the Raven software to make sound graphs, click the sound files listed below and listen carefully to each. As you listen, sketch a spectrogram predicting what you think the sound file will look like as a spectrogram on the computer.
 - Eastern Screech-Owl: These birds can be heard calling at all times of year in the eastern United States and southeastern Canada.

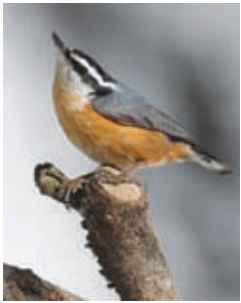
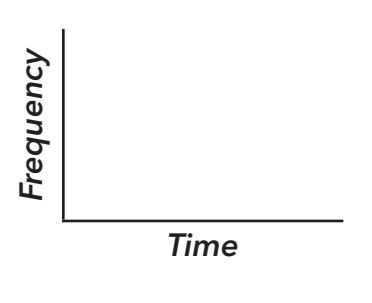

	Prediction	Actual
 TERRY SEARS		

Help your students: suggest that they look at the average frequency across the whole band covered.

SEEING SOUND


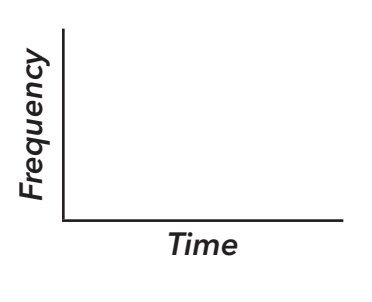
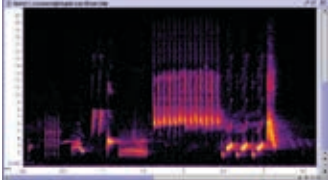
Worksheet: Answers

- b. **Red-breasted Nuthatch:** These birds are found in pine forests throughout western and northern North America.

	Prediction	Actual
		

Help your students: to get the proper numbers, they have to look at the very faint lowest bands, which don't show up uniformly in all parts of the recording. This may take some zooming and changing the brightness to find the lowest bands.

- c. **Common Nightingale:** Male nightingales sing long, complicated songs to attract mates. They are found in parts of Europe and Africa.

	Prediction	Actual
		

Help your students: given the complexity of this sound, drawing a detailed prediction for this one is unrealistic. Suggest plotting generalities.

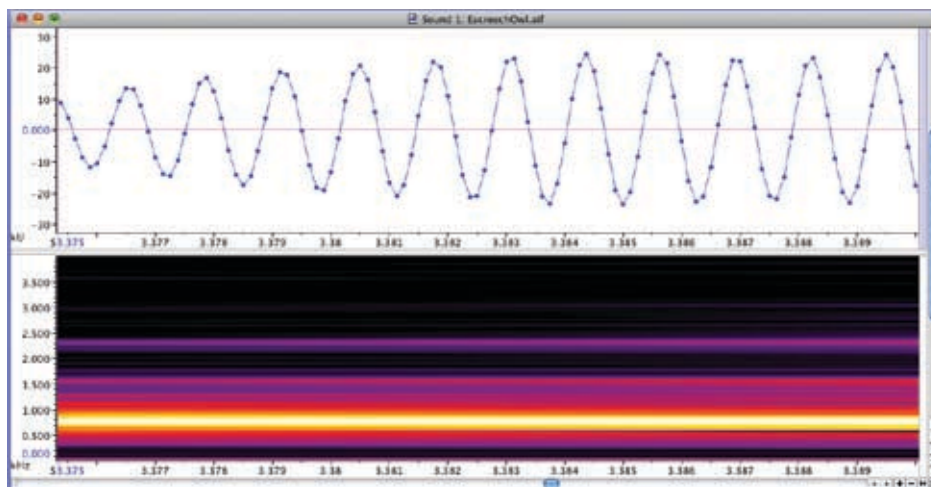
2. **Open each of the sounds in the Raven Lite software and look at the actual spectrograms.** Draw each in the space provided next to your predictions. To open sounds in Raven Lite simply drag them to the light blue Raven Lite window. How did you do? Was it hard to predict what the spectrogram would look like? Did you even try with the nightingale?


SEEING SOUND

Worksheet: Answers

Part 3: Measuring Bird Sound

You are ready to link the sound graphs to the physics of sound by making some measurements on waveforms and spectrograms of the bird calls you just listened to.



First open the Eastern Screech-Owl sound in Raven Lite and look at the waveform. Can you see how the owl makes a series of sound bursts? Now, zoom by clicking the  button on the toolbar until you see individual waves and blue dots appear on the waveform. Measure the time between two consecutive peaks of the waveform at a point in the sound when the peaks are most obvious to you and **record it in the Sample 1 data table below**—this is the period of one wave cycle (see diagram above).

Because Raven Lite does not give all the significant digits you need, estimate the start and end time as best you can—it will be just a tiny fraction of a second. Then measure the period of the screech-owl call in another part of the sound by scrolling forward using the bottom scroll bar and **record it in the data table for Sample 2.**

Now you will transform your period measurement into a prediction of the frequency (pitch) of the screech owl call. Frequency is a rate measured in Hertz. How can you translate a measurement of period into Hertz?

If your period was exactly one second, then the frequency would be 1 Hertz (1 Hertz = 1 cycle / 1 second), so all you need to do is **use the equation below to fill in the predicted frequency box in your data table:**

$$\text{___ Hertz} = 1 \text{ cycle} / \text{___ seconds (duration of period)}$$

SEEING SOUND

Worksheet: Answers

Data Table:

Sample	Period (seconds)	Predicted frequency from waveform (1 cycle/x seconds = Hertz)
	2.1194 - 2.1180 = 0.0014	1/0.0014 = 714
		Measured frequency from spectrogram (Hertz)
		731

Eastern Screech Owl	Period (seconds)	Predicted frequency from waveform (1 cycle/x seconds = Hertz)
	Example: 2.1194 end time - 2.1180 start time = 0.0014	1 cycle / 0.0014 seconds = 714 Hertz
		Measured frequency from spectrogram (Hertz)
		731 Hertz

Now, let's take a look at the Screech Owl spectrogram. Use the cursor to measure the frequency of the call and **record it in the data table for both samples**. Frequency in Hertz appears on the bottom left of the screen and looks like this: **Time: 1.000 S Frequency: 1709 Hz Power: 46.6 dB**. Note: Raven Lite displays frequency along the y-axis in Kilohertz (kHz), 1 kHz = 1,000 Hz.

How did your predicted frequency from the waveform compare to your measured frequency on the spectrogram? If you are within 30 Hertz you are doing a great job. You have completed the first step of what the computer is doing when it transforms waveforms into spectrograms. In practice, biologists use spectrograms more often than waveforms because frequency changes are obvious at a glance and can be readily measured.

Now open the Red-breasted Nuthatch call in Raven Lite and try to make the same period measurement on the waveform. You will notice as you zoom in that this waveform is more complicated than the screech owl's making it hard to choose where to measure the period. Try to answer the questions below as best you can.

1. Do the periods remain constant throughout the waveform? No
2. Now take a look at the spectrogram. What is the major difference between the nuthatch spectrogram and the screech-owl spectrogram? Multiple frequency bands in nuthatch call

The bands you see on the spectrogram are called harmonics. Look familiar? Our voices also contain harmonics, so you probably noticed them earlier when you were getting to know spectrograms. Many natural sounds contain harmonics, including musical instruments, such as guitars.

SEEING SOUND

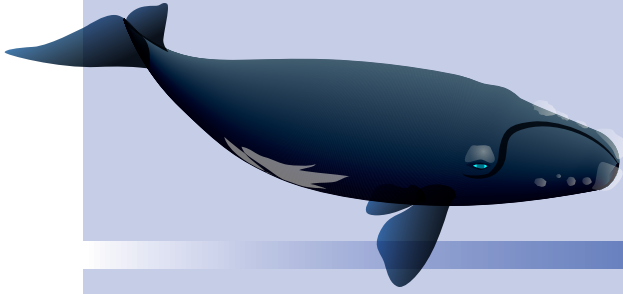
Worksheet: Answers

3. What is the frequency of the lowest frequency band? 480-520 Hz
4. Now measure the frequency of the next band above the lowest? 980-1020 Hz
5. Subtract #3 from #4. ~500 Hz (the same as the lowest frequency band!)

The answers to 3) and 5) should match because the spacing between harmonics is the same as the lowest frequency of the call. The regular spacing of harmonics is a result of natural vibrations of the vocal cords.

You don't need to measure the nightingale song but you can explore the different notes in his song (this is a male's song) by zooming in on each note and comparing the waveform and spectrogram. See if higher-pitched notes have shorter periods than lower-pitched notes.

SEA OF SOUND



SPEED OF SOUND

Teacher Notes

Before You Start

Time Frame

- Activity: 60 minutes.
- Teacher prep time: 1 hour

Grade Level: 10–11

Appropriate for grades 6–12, with extension activities.

Materials Needed

Teacher needs:

- Computer with working speakers attached to an LCD projector and loaded with the **Speed of Sound PowerPoint Presentation** of elephant and whale researchers at their field sites (in the resource section of the DVD or seaofsound.org).

Group needs:

- At least one computer with speakers or headphones.
- **RavenLite sound analysis software** loaded on computer. The program is available on the *Sea of Sound* DVD. It can also be downloaded for free: seaofsound.org
- To access the sounds for this exercise, in the **Raven Lite** “File” menu, choose “Open Sound,” then select the lesson’s folder.
- A **RavenLite Guide**
- Elephant and humpback whale sound files. Access these through the **Raven Lite** “File” menu by selecting “Open Sound File,” then the folder “Speed of Sound.”
- At least 1 map handout of field setup with positions of microphones and noisy animal. (**African Elephant Map** OR **Humpback Whale Map**)
- Calculator (optional)

Student needs:

- **Student Data Sheet**
- **Student Handout**

Overview

Students work in groups to conduct a mini-investigation during a class period. First students make predictions, then gather and integrate data from sound files and maps, and finally compare class results with initial predictions.

Learning Objectives

Students will:

- be able to recognize a waveform graph, explain what it measures, and use it to estimate the time of arrival of sounds at multiple microphones;
- be able to use maps to determine the distances between calling animals and the microphones;
- be able to estimate the speed of sound in air and water;
- evaluate their predictions about the speed of sound in air and water based on data gathered by the class;
- use the concepts of density and stiffness to explain the observed difference in the speed of sound in air and water.

Activity Overview

The physics of sound waves affects animals’ attempts to communicate with one another. For example, sound travels at different speeds depending on the physical properties of the medium it moves through. In this lesson, students use field recordings of elephants and humpback whales to compare the speed of sound in water to the speed of sound in air. This activity also exposes students to the nature of field biology through images, sounds, and videos from the scientific teams who gathered the field data.

Prior knowledge

Before beginning this activity, students should have familiarity with the following:

- **Mechanical wave:** Mechanical waves are produced when energy is added to a material, creating a localized vibration (the vibrating material does not move far from

its initial position). Once this initial energy is added, the wave will travel through the medium until all the energy has been transferred. Mechanical waves transport energy and not material.

- **Spectrogram:** A representation of a sound wave with time on the x-axis, frequency on the y-axis, and amplitude as a color scale. Any waveform can be mathematically broken down into individual frequencies and displayed in a spectrogram.
- **Waveform:** A representation of a sound wave with time on the x-axis and amplitude on the y-axis. Pressure increases and decreases at the microphone as sound waves pass by. These changes are turned into an electric signal and processed by a computer to show the waveform.
- **Speed of sound:** The rate at which sound travels through a medium (air, water, solid), usually expressed in meters per second.

Teaching Tips

- Please see suggested **Lesson Plan** for a detailed plan of how to use the activity in the classroom.
- Ideal group size is 3–4 students.
- Hook (2 minutes): To motivate students at the beginning of the lesson, you can play the clip of the eerily beautiful humpback whale song (**Humpback Whale Starting Sound Clip**). Each loud note is followed by a quieter version of the same note. If students listen without a verbal introduction, you can ask them to tell you what observations they made, what they think is making the noise, and why each note is repeated. You can refer to the responses later when they begin to work with sounds from near and distant microphones and explain that the recording is of one humpback whale named Lucifer. The echo effect is from the same sound being picked up on a more distant microphone about one second later. This sound clip demonstrates sound travel.
- Helpful questions:
 - How does sound travel from my mouth to your ear?
 - How long does it take? How could we find out?
 - Do we have to be in air for sound to travel? What else can sound travel through? Water, rock, space?
 - Does it always travel the same speed no matter what it travels through?
 - What might affect the speed that sound travels?
- The **Speed of Sound PowerPoint Presentation** contains notes below each slide explaining the content.

Extensions

- **Math-rich extension** (10 minutes): Use the alternate maps labeled with the x, y coordinates of the calling animal and microphone. Students use the Pythagorean theorem to calculate the distance between the points on their own.
- **Homework extension** (about 20 minutes): If you have time during a lab session or as homework, ask students to complete the synthesis questions on the back of the student handout. These questions are designed so that students have a chance to explain the phenomena they studied in their own words as well as think of unanswered questions and ways to test those questions.



Resources

- Reference tables for speed of sound in air and water: en.wikipedia.org/wiki/Speed_of_sound
- The Physics Classroom Tutorial Lesson 2: Sound Properties and Their Perception: <http://goo.gl/GKjgN>
- What is sound? Introduction by Matt Ottewill: planetoftunes.com/sound/whatsoun.html

National Science Education Standards

UNIFYING CONCEPTS AND PROCESSES: Evidence, Models, and Explanation; Change, Constancy, and Measurement

SCIENCE AS INQUIRY: Understanding About Scientific Inquiry—mathematics is essential in scientific inquiry. Mathematical tools and models guide and improve the posing of questions, gathering data, constructing explanations and communicating results.

PHYSICAL SCIENCE: Interactions of Energy and Matter—waves, including sound and seismic waves, waves on water, and light waves have energy and can transfer energy when they interact with matter.

LIFE SCIENCE: Behavior of Organisms—like other aspects of an organism’s biology, behaviors have evolved through natural selection. Behaviors often have an adaptive logic when viewed in terms of evolutionary principles.

SCIENCE AND TECHNOLOGY: Understanding About Science & Technology—science often advances with the introduction of new technologies. Solving technological problems often results in new scientific knowledge. New technologies often extend the current levels of scientific understanding and introduce new areas of research. Creativity, imagination, and a good knowledge base are all required in the work of science and engineering.

Standards-alignment matrices are available on the DVD or at seaofsound.org.

Acknowledgments

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SPEED OF SOUND

Lesson Plan

Elephants vs. Whales: Which sound travels faster?

What do you predict? Do elephant or whale sounds travel faster? Can you think of a reason why sound would travel faster in air or water? Think about sound as a mechanical wave; as it travels through a medium, molecules collide and send the energy of the wave outward from the source of the sound. What would make the sound travel more or less quickly? Once you have developed a prediction about the difference in elephant and whale sound speeds you will have a chance to measure the speed of sound in air and water yourself using recordings from central Africa and off the coast of Mexico.



In this investigation, you will:

- listen to elephant and whale sounds recorded on multiple microphones;
- measure the time it takes for sounds to travel between the microphones;
- measure the distance between the microphones;
- calculate the speed of sound in air and water;
- compare the speeds and explain any differences.

Materials:

- Raven Lite sound analysis software and elephant or humpback whale sound files
- A student data sheet
- A handout for the group showing when sound arrives at near and distant microphones
- A map handout for the group of field setup with positions of microphones and calling animal
- Calculator

Vocabulary:

Mechanical Wave: Mechanical waves are produced when energy is added to a material, creating a localized vibration (the vibrating material does not move far from its initial position). Once this initial energy is added, the wave will travel through the medium until all the energy has been transferred. Mechanical waves transport energy and not material.

Spectrogram: A representation of a sound wave with time on the x-axis, frequency on the y-axis, and amplitude as a color scale. Any waveform can be mathematically broken down into individual frequencies and displayed in a spectrogram.

Waveform: A representation of a sound wave with time on the x-axis and amplitude on the y-axis. Pressure increases and decreases at the microphone as sound waves pass by. These changes are turned into an electric signal and processed by a computer to show the waveform.

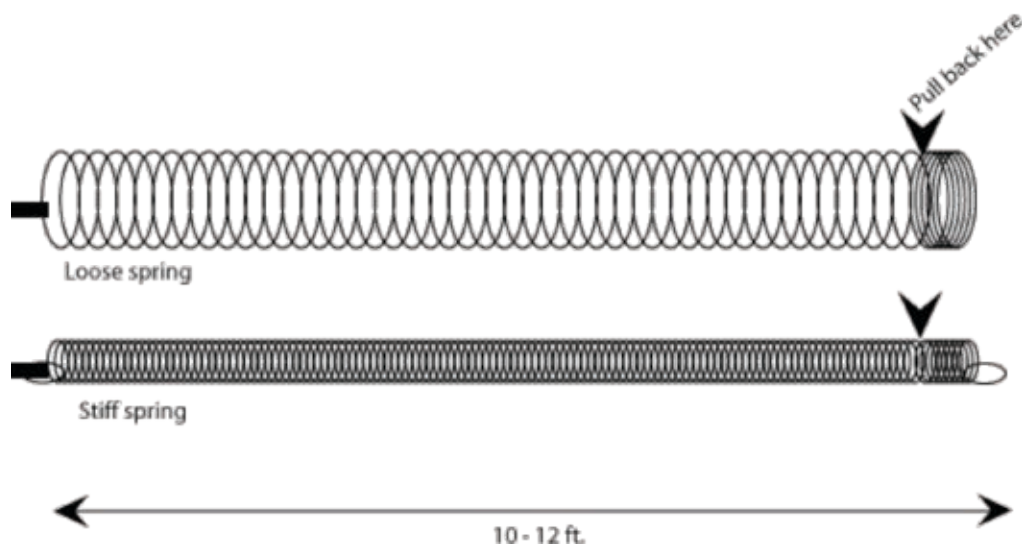
Speed of sound: The rate at which sound travels through a medium (air, water, solid), usually expressed in meters per second.

SPEED OF SOUND

Lesson Plan

Procedure:

1. **Guide student understanding of sound waves** (3 minutes): Sound is a compression of molecules traveling outward as a wave from a vibrating source. This may be a review of previous instruction.
2. **Prepare for student prediction with a thought experiment** (3 minutes): One analogy you can use for sound waves is people shoving in the back of a crowd and the shove spreading forward. The wave moves but the people don't.
 - Will the wave travel faster if people are densely packed or if they are loosely packed into the space? The more dense the crowd, the slower the shove moves forward because it takes more time for the extra people to be contacted by the shove.
 - Let's say everyone has their arms out in front of them. Will the wave travel faster if everyone has very stiff, straight arms or loose, bent arms? People with stiff arms have faster reaction times so the shove moves more quickly through the crowd if everyone's arms are stiff.
 - **OR use springs:** You can also use springs to demonstrate the speed of a sound wave as it varies based on the tension of the spring. You can do this using volunteers up front to help you stretch out the springs or you can have students try this themselves in groups. You are conducting a race to see which spring carries waves faster: the stiff spring or the loose spring. First, stretch out both springs along a countertop or along the floor so that they are the same length (~10–12 feet) and secure one end of each of the springs to the surface (or have someone hold it). On the other side, gather a few of the coils on each of the springs together and pull back. Then let go, sending a pulse down the springs simultaneously. Watch to see which pulse reaches the end more quickly. The wave travels down the stiff spring more quickly than the loose spring.



3. **Student predictions** (5 minutes): Using the student handout, have each student write down their prediction about whether sound will travel faster in air or water, including one sentence explaining why they think sound will travel faster in their chosen medium.
4. **Brainstorm ways to test student predictions** (3 minutes): Ask students to brainstorm ways to test their prediction. Guide students toward understanding that they need to measure:

SPEED OF SOUND

Lesson Plan

- the difference in arrival time between a near and a distant microphone hooked up to the same recording system;
- the extra distance traveled by the sound to a distant microphone.

Helpful questions:

- What equipment could we use to measure the speed of sound?
- What information do we need to collect?
- How is speed measured? (e.g. m.p.h., units of distance divided by units of time)

5. **Introduce students to the data they will use to test predictions** (10 minutes): In the Cornell Lab of Ornithology's Bioacoustics Research Program, researchers often gather recordings of vocalizing animals on multiple microphones at the same time. The students will use recordings to measure the speed of sound. As a way to create interest in the topic and teach about the nature of science, lead students through the presentation showing where and how the elephant and humpback whale data were collected. In each case, field scientists noted and recorded the position of an individually-known animal making sounds. Through the presentation, you will explain the stories of Greyboy the elephant and Lucifer the humpback whale. As part of this presentation, you will also teach students about the graphical representation of sound using waveforms.
6. **Student data collection** (10–15 minutes): Divide students into groups of 3–4 students. Have half the groups work on elephant sound and half on whale sounds. Give them 15 minutes to collect data from the maps and sound files. The student handouts provide a structure for data collection. Students using computers should have the Raven Lite instructions handy in case they have questions about the software. If you would like students to work in a less guided way, you may choose not to have students use the handout.

In each group, students use the waveform plot to measure the difference in the arrival times of sounds arriving at a microphone near animal and a microphone farther from the animal. Because the acoustic recorders were precisely time-aligned, the difference in arrival times represents the extra time (in seconds) it took for a sound to reach the distant microphone. It is, however, somewhat challenging to decide exactly when a sound starts on the waveform plots. Each student will make a slightly different decision. By averaging time estimates from each student, groups should come up with a reasonable value. Based on maps showing the microphone and animal positions, students calculate the extra distance (in meters) traveled by the sound to the second microphone. Students combine this information in a speed-of-sound estimate for either an elephant sound in air or a whale sound under water.

If you plan to use the **Math-Rich Data Extension**, use the alternate maps labeled with the x, y coordinates of the vocalizing animal and microphone and have students use the Pythagorean theorem to calculate the distance between the points on their own (*African elephant_map_xy* or *Humpback_whale_map_xy*).

7. **Group reporting** (5 minutes): Ask students to report group results back to the class. Compare the speed of sound results from elephant teams to those from the whale teams. Come to a consensus about whether sound travels faster in air or water and what the rough estimates are (in meters per second) for sound speed in these environments. If values are very different from those in the chart below, you may want to work with particular teams to see what happened.

SPEED OF SOUND

Lesson Plan

Speed of sound:	Air	Seawater
Range	325-355 m/s	1,400-1,700 m/s
Specific values for sound files used	340 m/s	1,550 m/s

8. **Synthesis** (5 minutes): To wrap up, ask students to reflect on whether the results they gathered supported the prediction they made at the start. Then guide students through the logic of **why** sound travels roughly five times faster in water. As you established earlier, the more dense the medium, the slower the sound travels because it takes more time for the more densely-packed molecules to interact and move the wave forward. Water is more dense than air yet sound travels faster in water. So what is going on? The more stiff the medium the faster the sound travels, because stiff things transmit energy faster and more efficiently. In this case, the stiffness of the water in comparison to the air is more important than density in determining sound speed. Stiffness trumps density.

Helpful questions:

- For how many of you did your results support your predictions?
- If water is more dense than air, why is sound moving faster in air than water?

Math-rich extension: (an extra 10 minutes or so)

Discuss the results from your investigation in terms of the equation for sound speed. In general, the speed of sound c is given by:

$$c = \sqrt{\frac{C}{\rho}} \quad \text{where } C \text{ is stiffness and } \rho \text{ is density}$$

This equation expresses mathematically the basic relationships between stiffness, density, and the speed of sound. As stiffness increases so does the speed of sound. Because density is in the denominator, as density increases the speed of sound decreases. If you want to devote more time to exploring this equation, you can ask students to look up density and stiffness measures for air and water to see if they can calculate the speed of sound for air and water this way rather than empirically measuring it as we did above.

Answer Key

Although students will not come up with the perfect values for speed of sound because of start time measurement error, they should fall in the ballpark of the values in the table below. If values are hugely different from those in the chart below, you may want to work with particular teams to see what happened.

Speed of sound:	Air	Seawater
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SPEED OF SOUND

Student Handout

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SPEED OF SOUND

Student Handout

Procedure:

1. Start the sound analysis program

Open the program Raven Lite by selecting it from the list of installed programs or clicking on the  icon.



2. Open the sound files


You will now open two sound files, one recorded by a microphone near the animal and one from a microphone farther from the animal. You can open sound files by dragging them into the Raven program window or by using the File menu, selecting Open Sound Files, and finding the folder on your computer where your teacher is storing the sound files. The names of the two files you should open are in the table below. Find and open the files that match the animal your group is studying.

Group:	Open the sound files named:
Elephant	African_elephant_near_microphone.aif African_elephant_far_microphone.aif
Whale	Humpback_whale_near_microphone.aif Humpback_whale_far_microphone.aif

3. Analyze your sound

You will have two windows on your screen showing graphs of the sound from the near and the distant microphone. Each window has two graphs: the blue one on top called a waveform and the colorful one on the bottom called a spectrogram.

For a less busy screen, hide the bottom graph in both sounds by clicking the  button on the top toolbar. Now, look at the sound file graph from one of the microphones. On the waveform that is now filling your screen, you are seeing time plotted from left to right and loudness plotted from bottom to top. When a loud sound is recorded, we see it as a burst of blue on this graph. Play the sound in by clicking the  key from the upper toolbar. What does it sound like? Now measure the time it took for the sound to arrive at the near microphone by dragging the vertical pink line hiding at the left edge of the graphs to the point on the graph exactly where you think the sound first began. Your measurement is shown in blue on the x-axis in terms of seconds from the beginning of the sound file.

You may want to expand the time scale to get a closer look by pressing the  button on the toolbar. Make this measurement three or four times on each recording, letting each group member take a turn, and record the measurements on your data sheet. Repeat this process for the sound recorded on the distant microphone. Then calculate an average difference in time of arrival between the two microphones.

4. Calculate distance

Look at your map of the recording setup and calculate the extra distance in meters traveled by the sound to the distant microphone in comparison to the near microphone and record this on your data sheet.

5. Estimate speed of sound

You are ready to estimate speed of sound in air and water (in meters/second) based on your data.

SPEED OF SOUND

Student Data Sheet

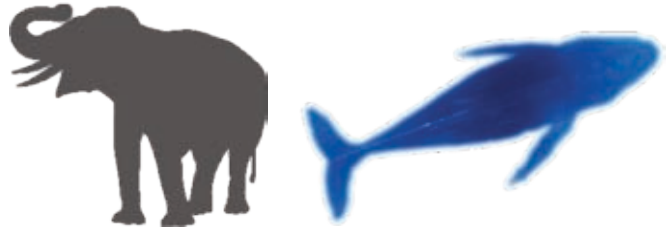
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Prediction:

I predict sound travels: (choose one)

- at the same speed in air and water
- faster in air than water
- slower in air than water

because: (explain using words or drawings)



Data Collection:

Environmental Studied:

Observation	Near microphone start time	Distant microphone start time	Average difference in time of arrival	Extra distance traveled to distant microphone	Estimated speed of sound
Person 1					
Person 2					
Person 3					
Person 4					
Average					

Synthesis:

Does the class agree your prediction?

SPEED OF SOUND

Student Data Sheet

Explain your results in terms of the physics of sound waves.

(e.g. The speed of sound is faster/slower in air/water because...)

Write down a question you have about the speed of sound.

How would you go about finding the answer?

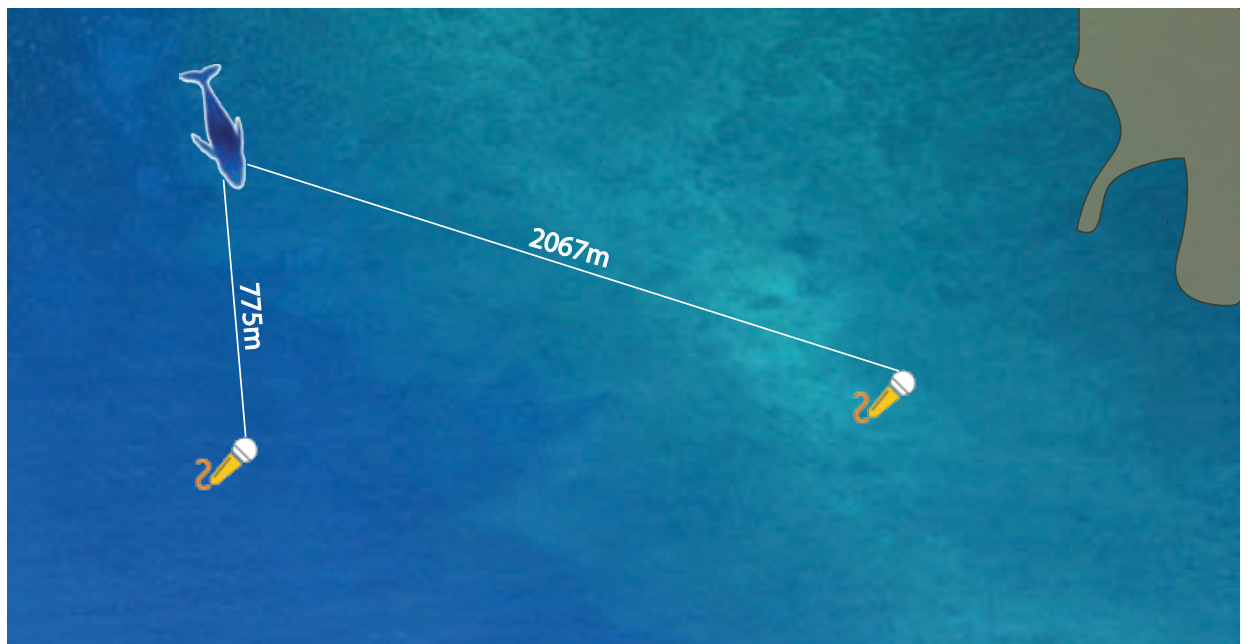
SPEED OF SOUND

Student Handout: Maps

African Elephant Map



Humpback Whale Map



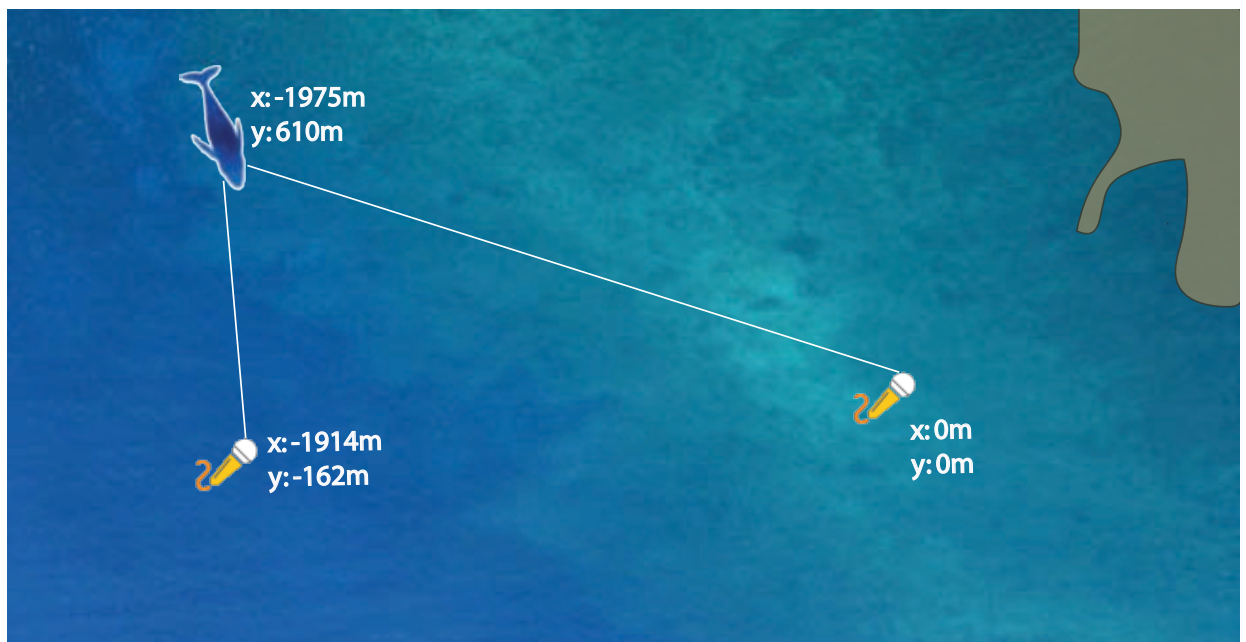
SPEED OF SOUND

Student Handout: Maps—Math-Rich Extension

African Elephant Map—x, y Coordinates



Humpback Whale Map—x, y Coordinates



SPEED OF SOUND

Student Handout: Raven Lite Guide

Full documentation at www.birds.cornell.edu/brp/raven/RavenDocumentation.html

At-a-glance guide to Raven Lite

Menu (File, Edit, View, Window, Help)

Toolbar (Play, Stop, Speed, Brightness, Contrast, Detail)

Sound (Waveform view, Spectrogram view)

Waveform (Loudness (Amplitude) in kU, Time in Seconds)

Spectrogram (Pitch (Frequency) in kHz, Time in Seconds)

Measurement bars (drag the purple lines to desired point in time, frequency or amplitude and read result on the axis (in blue))

Zoom options (2048)

Rate: 1.0

Lines: 1

Time: 16.482 S Minimum: -2427 Maximum: 2318