Listening to Fish: New Discoveries in Science

By Rodney Rountree, Ph.D.

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Introduction

Have you every heard the phrase "cutting edge science?" That's when scientists are learning things no one ever knew before. They are exploring new ideas and making new discoveries. We never quite know where the next area of cutting edge science is going to be. Its difficult to predict. In this book you are going to learn about some exciting cutting edge science in the field of marine biology. You will learn things that most people don't know, even most scientists! Not long ago a famous marine scientist and explorer named **Jacques Cousteau** wrote about the beautiful silent world under the oceans. His "Silent World" became a popular catch phrase. You see, Cousteau was an expert undersea diver and explorer who made many underwater films and taught millions of people about the wonderful world under the sea. When I was a young boy, I loved to watch his shows and in fact, he was one of the people that inspired me to become a marine biologist. But what Cousteau did not know was that the undersea world only seemed silent to him because his SCUBA equipment and dive vessels were so noisy that they drowned out the sounds of undersea life. That's right, it really is a very noisy world under the sea. All kinds of things make sounds under the sea, including some fishes. To be sure, Cousteau was familiar with whale sounds, and worked extensively with the big mammals, but he overlooked the importance of other undersea sounds until later in his long career.

Many animals make sounds because of their activities. For example, fish can be heard as they feed when they bite and grind food in their teeth. Sometimes you can hear the sound of fish swimming, especially if the fish makes a rapid motion, or if many fish move at the same time.

And believe it or not, scientists recently recorded the sound of a fish farting! Is that cool or what? Other types of animals also make incidental sounds like these. A type of shellfish known as "**mussels**" make loud snapping sounds when they move. Normally a mussel is tightly anchored to a rock by what are called "**byssal threads**." In order to move, the mussel has to snap off the threads one at a time and then re-anchor itself with new threads. When hundreds or thousands of mussels do this at the same time within mussel beds, it can be heard as a continuous crackling sound. Another type of marine animal that is famous for its sounds is a type of small shrimp known as the **snapping shrimp**. Often thousands of these little shrimp can be heard snapping at the same time, creating a very loud noise.

Mussel and byssal threads (Image courtesy of Genny Anderson at http://www.biosbcc.net/ocean/flhi.htm)

Snapping shrimp

(Reprinted with permission from Southeastern Regional Taxonomic Center/South Carolina Department of Natural Resources).

But not all underwater sounds made by animals are accidental. Many animals, especially fish, make sounds on purpose. Sometimes this is called "**vocal behavior**," but because fish do not have the vocal chords familiar in humans and other mammals, scientists often refer to fish vocal behavior as "**soniferous**" behavior (soniferous just means "sound-making"). Fishermen and scientists have known for centuries that some fish make sounds. The great Greek scholar

Aristotle described some fish sounds over two thousand years ago. Several types of fishes are named after the sounds that they make, including the "croakers," "drums" and "grunts." In recent years, scientists have begun to realize the importance of underwaters sounds. Now a few scientists around the world are using underwater sounds as a way to explore the seas and make new discoveries. How are they doing that? Simple, by listening. Want to find where a fish lives? Then try listening for its calls or other sounds it makes. Want to find where a fish **spawns**? Try listening for its **courtship** sounds. In this book you will be introduced to some of these fish sounds, and the ways that scientists are using them in cutting edge research. Today the science of listening to fish sounds is called "**passive acoustics**."

Hiding a submarine?

When submarines became important weapons in World Wars I and II, the science of undersea **acoustics** took on great importance to the United States Navy. Since submarines travel under water, they were very dangerous because ships could not see them approach. So one of the best ways to guard against a submarine attack was to listen for the sound of the submarine. It became very important to be able to tell what a submarine sounded like and how to distinguish its sounds from those of other ships and from other underwater sounds. But when naval officers began listening for submarines, they were confronted with a multitude of unknown undersea sounds. Scientists around the world were quickly enlisted to help the various navies to figure out what they were hearing. Sometimes natural sounds were so loud that they could "mask" the sounds of a submarine. Submarine commanders would try to take advantage of various underwater noise sources to cover the sound of the sub. One team of scientists at the University of Rhode Island was commissioned by the United States Navy after World War II to investigate biological

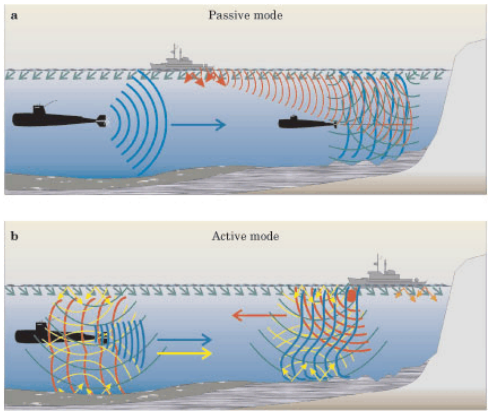


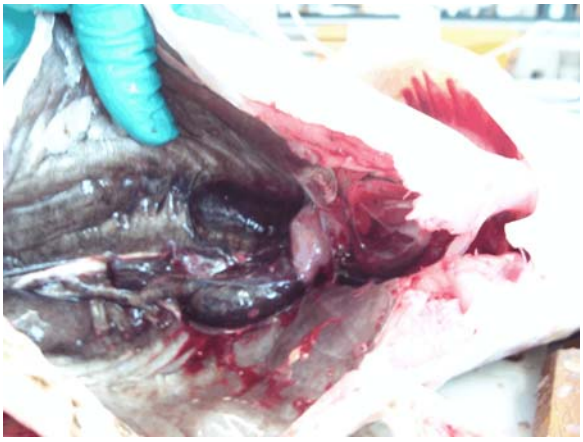
Illustration of how sound is used in antisubmarine warfare. In the top figure, a ship tows hydrophones to listen for sub sounds (blue waves) that is distorted by the shallow-water environment and embedded in ocean surface noise (green arrows) and shipping noise (red waves). In the bottom figure a ship using active sonar (similar to depth gauges and fish finders), that sends out a pulse of sound (red waves). The ship then listens for the echo off the sub (blue), which is distorted by the shallow-water environment, other echos (yellow) and ocean noise (green). (Reprinted with permission from Kuperman, W.A., and J.F. Lynch. 2004. Shallow–Water Acoustics. Physics Today (Oct. 2004):55-61. Copyright 2004, American Institute of Physics.).

sources of sounds in the Atlantic ocean. Drs. **Marie Fish** and **William Mowbray** conducted top secret research for the Navy for a number of years. In the 1960s much of this work was declassified and the team began working to develop a catalog of the sounds of undersea fishes. They published an important book in 1970 that examined the sounds of more than a hundred **species** of fishes. But they also collected an extensive archive of other undersea sounds from their own research as well as from the work of other researchers around the world. Unfortunately, their work was largely overlooked and forgotten for the last few decades, but then in 2001 a group of scientists rediscovered the Fish and Mowbray archives and began working to rescue them and make them available to the public. The MaCaulay Library of the Cornell Laboratory of Ornithology has recently made a large collection of fish sounds from these archives available to the public. You can go online at http://www.birds.cornell.edu/MacaulayLibrary/ and listen to the sounds of many different types of fishes, seals, and whales recorded by these early researchers as well as by many other researchers around the world today. Another good web site is Discovery of Sounds in the Sea.

How do fish make sounds?

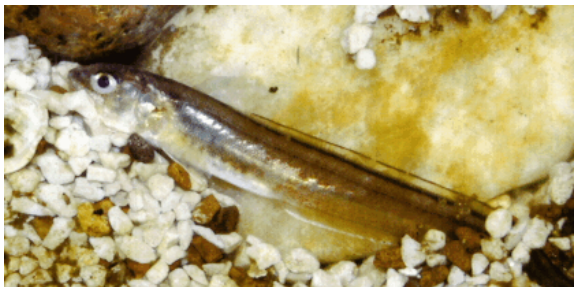
There are many ways in which a fish can make sound. In some cases, sound is produced simply because of something the fish is doing, like swimming or eating (or perhaps farting!). These sounds are called incidental sounds because they are not made on purpose by the fish for communication. However, they still can be used by scientists to learn about the fish. Listening to the feeding sounds of a fish can tell us when and where it feeds in the wild, something that is very difficult to figure out using other methods. But many sounds are produced by fishes when they are scared (disturbed), mad (aggression), or during courtship (trying to attract a mate). **Stridulation** sounds are made by rubbing body parts together, like crickets rubbing their hind legs together. Stridulation sounds are most often described as rasps, creaks or grunts. Most commonly, fish grind their teeth together or flick their fin spines. In many cases these stridulation sounds are picked up and amplified by the **swim bladder**. The swim bladder is an air-filled sac found inside the body of many fishes. It acts kind of like a drum to amplify the sounds. However, not all soniferous fish have swim bladders. The long-horn sculpin, for example makes a humming sound. It's not very loud, but if you hold the fish in your hands, you can feel the strong vibrations. In fact, fishermen have given the fish the nickname of "buzz-bomber" because holding one of these fish feels like you're holding a bomb. Many other fish,

like drums, cusk-eels and toadfish, have special muscles called **sonic muscles** that push on the swim bladder to create loud sounds. These sounds are often characterized as drums, croaks, and thumps.



Haddock sonic muscles (Katie Anderson).

The little cusk-eel



Cusk-eel (Rodney Rountree)

One very interesting soniferous fish is the striped cusk-eel. Its current **scientific name** is *Ophidion marginatum* (which means "margined snake"), but it used to be called *Rissola marginata* (it was named after the French **ichthyologist** Anatole Risso who worked in the Mediterranean in the early 1800's). It is a member of the cusk-eel Family of fishes known by scientists as **Ophididae**. There are many species of cusk-eels around the world, and many are found in the deepest parts of the ocean. Many years ago scientists studying the anatomy of fishes discovered that the striped cusk-eel, and other members of the cusk-eel family, had special muscles that they thought were used in making sounds. But no one knew for sure because their sounds had never been recorded.

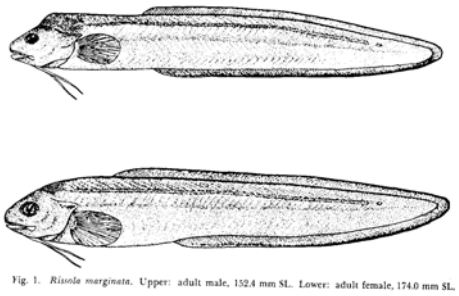
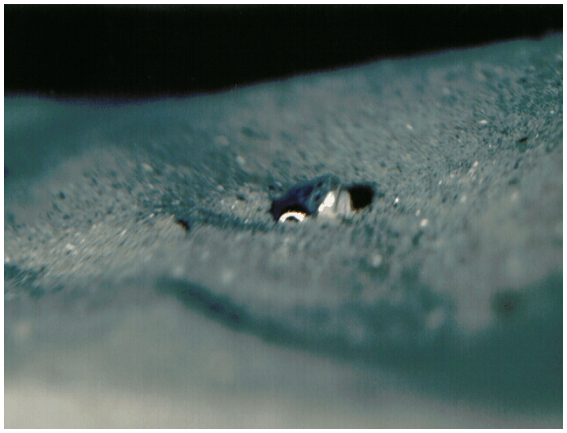


Fig. 1. *Rissola marginata*. Upper: adult male, 152.4 mm SL. Lower: adult female, 174.0 mm SL.

Male and female striped cusk-eels (From Courtenay 1971)

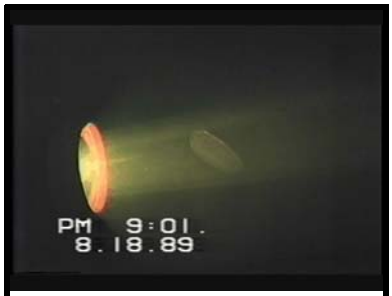
Well, a few years ago I had an opportunity, along with a colleague of mine named Jeannette Bowers-Altman, to study the behavior of the striped cusk-eel at Rutgers University in New Jersey. We kept several male and female fish in the laboratory for a couple of months one summer and observed their spawning behavior (what the fish does when it lays its eggs). We could easily tell the males from the females because the males have a large bump on their heads.



Cusk-eel emerging from his burrow (Rodney Rountree)

The cusk-eels would hide by staying buried under the sand all day but would come out at night to lay eggs and feed. It was exciting to be the first people to record the spawning behavior of these little fish, but what was even more exciting was that we could hear the fish making loud sounds each night before spawning. They sounded a lot like woodpeakers. Some people think they sound like a jackhammer. As far as we could tell, only the males made the sounds. They always started calling at the same time every night. And you know what? The cusk-eels would start calling while they were still hiding under the sand! Then they would slowly poke their heads out of the sand and continue calling. We think the males use the calls as part of their courtship behavior. They behave very much like frogs, with males making loud chorus calls at sunset to try and attract a female for spawning.

Silent video of spawning cusk-eels. The large individual is the female, and the smaller one with the hump on its head is the male. (Rountree and Bowers-Altman)



Cusk-eel egg mass (Rountree and Bowers-Altman)

Click to play sounds:

single cusk-eel call

cusk-eel chorus

Rodney Rountree (http://www.fishecology.org)

Some time later our colleague **David Mann** found out about our recordings of cusk-eel sounds, and together we published the first paper describing them. Then we found out that other people had been hearing cusk-eels in the wild for many years, but they did not know what the sounds were. In fact, our striped cusk-eel became kind of famous because some scientists had mistaken their sounds for other fishes such as searobins and weakfish. But sure enough, after we found out what cusk-eels sounded like, people from all over started coming to us and saying they had heard the fish too. For example, people that lived in sailboats told stories of hearing a strange sound at night on their sailboats, but no one ever knew what it was. Imagine their surprise when they found out that the little cusk-eel was the thing that was making all that noise at night!

Map of Cape Cod (Courtesy of Wikimedia Commons)

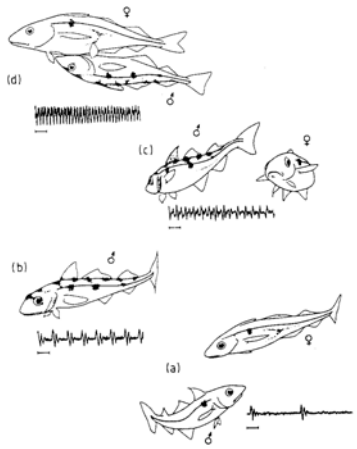
Click to go to an online satellite view.

And when we started listening to fish on Cape Cod in Massachusetts, we were very surprised to find the same sounds all over the place because no one knew striped cusk-eels were there. One of the places we heard striped cusk-eels on Cape Cod was in Woods Hole, Massachusetts. You may have heard of Woods Hole because it's famous for its international research institutions, including the **Marine Biological Laboratory**, the **Woods Hole Oceanographic Institution**, and the **Woods Hole Laboratory of the National Marine Fisheries Service**. The striped cusk-eel sure must be a sneaky fish to be able to hide from all those scientists for over a hundred years!

Haddock

Haddock (Rodney Rountree)

Haddock, *Melanogrammus aeglefinus* (which means black mark and bright fin), is an important fishery species on both the North American and European sides of the Atlantic Ocean, but its abundance has declined in recent years. Despite a long history of study, we still don't know much about the spawning habits or habitat requirements of haddock. Females can start spawning when they are about 2 years old and 15 inches long. They spawn in the middle of winter out in the ocean. Do you think maybe that's why we don't know much about them? Haddock, like many other fishes in the Family **Gadidae** are known to be vocal. **Tony Hawkins** of the Fisheries Research Laboratory in Scotland has been studying the sounds of haddock for many years. He found that haddock have a special sonic muscle that they use to make drumming sounds. Mostly only the males make sounds to attract females during courtship, but females can make some sounds when either mad or frightened. The males stake out territories and make a thumping sound to try to attract

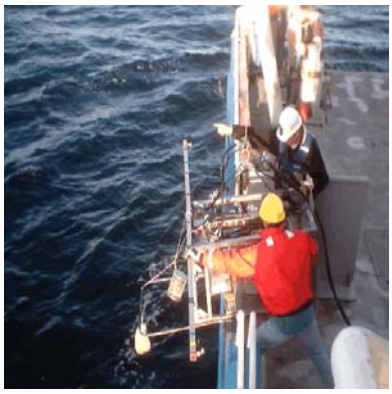


Courtship behavior of haddock (from Hawkins 1986).

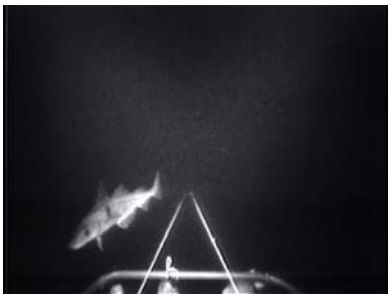
Listen to a haddock call
(Courtesy, Tony Hawkins)

females. If a female comes over, the male gets exited and the thumps become faster and faster until they sound like a rumble or drum-roll.

In the United States, scientists like myself, **Cliff Goudey** at the MIT Center for Fisheries Engineering Research and **Francis Juanes** at the University of Massachusetts at Amherst are using advanced undersea technology to spy on haddock on the fishing grounds off Massachusetts to determine when and where haddock spawn. Fisheries managers need this type of information to protect haddock spawning areas so the population can recover. So far it looks like haddock are vocal mostly in the late afternoon and early evening, so we think maybe that's when spawning occurs.

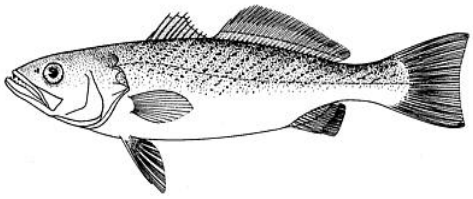


Deploying an acoustic array aboard the R/V Connecticut (Rodney Rountree)

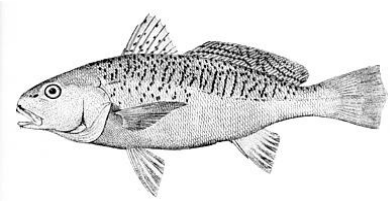


Haddock attracted to baited camera on Stellwagen Bank (Rodney Rountree). Click image to see video clip.

Croakers and drums



Weakfish or gray trout



Croaker

Croakers and drums (the **Sciaenidae** family of fishes) have been known to produce sound for centuries. The ancient Greek philosopher and scientist **Aristotle** discussed them thousands of years ago. For hundreds of years the Chinese have found where drums spawn by listening to drumming sounds from the water through the hull of their boats. In fact, the family is named after the croaking and drumming sounds that many of its members make. If you have ever been fishing on the seashore and estuaries of the Gulf and Southeastern coasts of the United States, then you've likely caught one of these fish and heard its distress call. There are many common species, but some of the most important include the spot (yes, that's the name of a fish), Atlantic croaker, silver perch, weakfish (also called the gray trout), speckled trout, red drum and black drum.

Drum aggregation (Grant Gilmore)

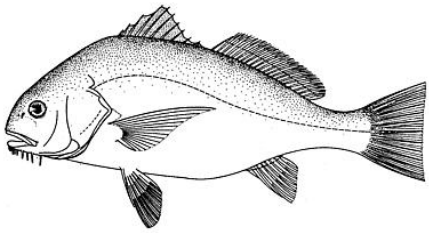
Scientists believe that most of the 270 species in this family probably produce sound using **sonic muscles** associated with the **gas bladder**, but only a few species have actually been studied. Now scientists like **Grant Gilmore** (Estuarine, Coastal and

Ocean Science, Inc.), **David Mann** (University of South Florida) and **Joe Luczkovich** (East Carolina University) use hydrophones to map the spawning habitats of drum fishes so that they can be protected. Large chorus aggregations of male spotted seatrout, weakfish, red drum and silver perch form specifically to attract females for spawning. Chorus aggregations are where hundreds or even thousands of fish gather together and call at the same time to attract females. Amazingly Dr. Gilmore has found chorus aggregations to return to the same locations again and again for more than twenty years!

Listen to a weakfish call

Listen to a weakfish chorus

Courtesy Joe Luczkovich. For more information go to Joe's web page at: http://core.ecu.edu/BIOL/luczkovichj/fishsounds/fish_sounds.htm



Black drum

If you live in Florida, you may have heard about the problems one town has had with noisy black drum, *Pogonias cromis* (which means "bearded sea-fish"). It seems that many people built homes on a network of canals in an estuary south of Tampa. Well, it turned out that black drum really likes to use those canals to set up chorus aggregations. The problem is that the steep, man-made walls of the canals allow the sound from the chorus to travel into the houses that people built along the canal, so the people could hear the fish sounds in their homes, too! Residents at first did not know what was making the awful sound. It was very

Click to hear the sound of black drum (Courtesy Joe Locascio). For more information go to Dave Mann's web page at: http://www.marine.usf.edu/bio/fishlab/

annoying and made it hard to sleep at night. They complained to the police, to town officials, and anybody else that would listen. Finally, Dr. David Mann and his student Joe Locascio from the University of South Florida were sent to investigate. Imagine everyone's surprise to discover that the black drum fish were making the sound! A similar problem happened years ago in California because of the midshipman. You can read about that in the toadfish section of this book.

Toadfish and midshipman

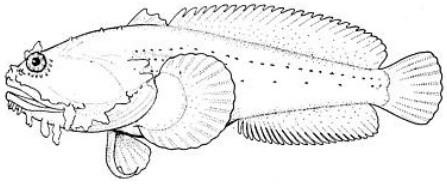
Toadfish and midshipman are well known sound producers in the Family **Batrachoididae**. One species of midshipman, *Porichthys notatus* (which means "remarkable pored fish"), on the Pacific coast is known as the "Californian singing fish" because its courtship humming can often be heard at night along the seashore. The midshipman gets its name from large pores that line its undersides and reminded scientists of the buttons on the uniform of sailors back in the 1800s (the sailors were called "midshipman"). During May and June the midshipman migrates into shallow coastal areas from offshore. The males call to attract females to their nests made under rocks in the shallow water. Back in the 1980s the midshipman became famous because people that lived along the shoreline kept hearing a strange humming sound at night. No one knew what it was and people began to imagine all kinds of things. Some people thought the sounds came from Russian ships ready to invade California, or from alien UFOs, or from secret US military maneuvers. No one imagined that the sound could come from the little midshipman! But once marine scientists began to investigate, they found that an unusually large number of

Midshipman and nest. For more information go to http://www.news.cornell.edu/releases/June98/hummingfish.hrs.html (courtesy Andy Bass).

Click to hear the hum sound of the midshipman

(more sounds can be found at: http://www.news.cornell.edu/releases/June98/hummingfish.hrs.html)

midshipman were making their nests along the seashore that year and their combined calls resulted in the strange humming sound people were hearing. Dr. **Andy Bass** of Cornell University has been studying the behavior of midshipman for years. He has conducted both laboratory and field studies using fish models and playback experiments (that's when you play a copy of the fish sound underwater and see how the fish reacts) to demonstrate that the male fish makes a call that resembles a foghorn to attract females. When the females hear the call being broadcast by an underwater speaker they are attracted to the speaker.



Oyster toadfish

On the east coast of the United States the toadfish, a relative of the midshipman, has also been extensively studied. For many years, Dr. **Michael Fine** (Virginia Commonwealth University) has been studying how and why toadfish make sounds. Like the midshipman, male toadfish make nests under rocks and call to attract females with a foghorn sound. Both males and females make grunting sounds when disturbed, but only the males make the foghorn sound. There are several species of toadfish which all look

Toadfish in nest (courtesy NOAA and Narragansett Bay Estuary Program)

Example of toadfish juveniles in the nest (Courtesy The Breeder's Net by Martin Moe in the March 2003, Advanced Aquarist's Online Magazine)

very similar, but have different foghorn calls. The oyster toadfish, *Opsanus tau*, is perhaps the best studied species. The name comes from the Greek language. *Opsanus* means "eyes upward," which refers to the fact that the eyes of the toadfish are both on top of its head. But *tau* simply refers to the 19th letter of the Greek alphabet, so I guess the scientist that described this species just liked the sound of the word *tau*! The oyster toadfish produces a simple foghorn call with a single long "boop" sound. Other species tend to have more complicated sounds that consist of a combination of grunts followed by a series of short boop sounds. For example, although the oyster toadfish and Gulf toadfish (*Opsanus beta*) look almost identical, they have very different calls.

Photo of the oyster toadfish, *Opsanus tau* (Courtesy of NASA and Wikimedia Commons).

Photo of Gulf toadfish *Opsanus beta* (Courtesy of Wikimedia Commons).

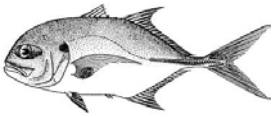
Click to hear Oyster toadfish sound recorded by Rodney Rountree on Cape Cod, Massachusetts.

Click to hear Gulf toadfish recorded by Rodney Rountree in

Other vocal fish

Scientists have just begun to catalog vocal fishes, and no one really knows how many there are. Marie Fish and William Mowbray published a book on vocal fishes of the Atlantic Ocean back in 1970 that listed 150 species of vocal fishes, but that's probably a vast underestimate. There's not enough space in this book to cover all these species, so I'll just mention a few here.

Jacks

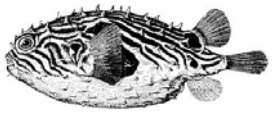


Caranx hippos

Click to hear sound. (From the Fish and Mowbray collection courtesy of URI)

Jacks belong to the family **Carangidae**, which has about 140 species. These are strong, fast-swimming species that are usually pelagic (they live in the water column above the bottom, as opposed to benthic fishes that live on the bottom) and often swim in schools. Some are popular sports fish such as the amberjack, pompanos and permits. Marie Fish and William Mowbray list 15 soniferous jack species, but many more species are likely to make sounds. Most species have just not been studied. Jacks appear to produce stridulation sounds by grinding their teeth. The Crevalle Jack, *Caranx hippos*, a common species found as far north as Cape Cod in the summer, is highly soniferous even as a juvenile. The name comes from a Portuguese word for jacks ("*caranx*") and the Greek word for

horse ("*hippos*") and means "horse jack."



Striped burrfish

Puffers and burrfish

Puffers and burrfish, also known as blowfish and porcupine fish, are members of the families Tetraodontidae and Diodontidae, respectively. There are about 121 species of puffers and 19 species of burrfish. The family names come from the Greek "tetra" (meaning four), "odontos" (meaning tooth) and "di" (meaning two), so Tetraodontidae means "four-toothed" and Diodontidae means "two-toothed," which describes how scientists tell the two groups of fishes apart. Fish and Mowbray listed five species of puffers and three species of burrfish as vocal, but most species have not been studied. The northern puffer, *Sphaeroides maculatus* (which means spotted ball fish or globefish), is an important recreational fish on the east coast of the United States. Its disturbance call has been said to sound like a "wet sneaker."

Norther puffer.

Click to hear sound. (From the Fish and Mowbray collection courtesy of URI)

Damselfish

Damselfish are members of the family Pomacentridae, which includes about 315 species of tropical fish many of which are popular in the pet trade. These include the anemone and clown fishes (like Nemo in the Walt Disney movie "Finding Nemo"). Fish and Mowbray listed 4

vocal species, but many other vocal species have since been identified by Dr. **Phil Lobel**, Dr. **David Mann** and others. One popular damselfish commonly found in pet stores is the domino damselfish, *Dascyllus albisella*. The genus name comes from the Greek "daskillos" which means "a kind of fish" and the species name comes from the Greek "albus," which means white and "sella" which can mean "saddle." So one translation of the scientific name is "fish with a white saddle mark" which describes the large white spot on the fish's side. *Dascyllus albisella* is a common reef fish from the Hawaiian Islands. Its Hawaiian name is "'alo'ilo'i." Males of this little damselfish make courtship sounds to attract females to their nests.

Click to hear sound

Searobins

Prionotus evolans

Searobins are members of the family Triglidae, which contains about 100 species. Fish and Mowbray list two vocal species, but they did not examine other species. Later **Tony Hawkins** and his colleagues described another species. Searobins are characterized as being very vocal species, and it is amazing that so few have been studied by scientists. The two species that Fish and Mowbray studied are both very common on the east

Click to hear sound recorded on Cape Cod, MA (Rodney Rountree)

coast of the United States and are often caught by fishermen on beaches and in estuaries. Unfortunately, even though they are good eating, they are considered trash fish because their large head and strong spines make them difficult to fillet. After hearing a striped searobin, *Prionotus evolans*, call in the wild for the first time, I wondered why they were not named "sea chickens" instead of searobins, because they seemed to me to cackle like chickens! The name comes from the Greek "*prionotus*" which means saw-backed, because of its large spines, and "*evolans*" which means flying, because of its large wing-like fins.

Conodon nobilis
(Drawing courtesy of www.fishbase.org.)

Grunts

There are about 150 species of grunts in the family Haemulidae. These tropical fishes are called grunts because many of them make loud grunting sounds when caught. The Family name means "bloody gum" because the inside of the mouth of some species is bright red. There are about 150 known species. Fish and Mowbray listed 15 vocal species, but again, few have been studied for sound production by scientists, and many more species are probably soniferous. Sounds made by the barred grunt, *Conodon nobilis* (which means noble cone-tooth), are a good example for the group.

click to hear sound from the Fish and Mowbray archives (Courtsey URI).

Pioneers in passive acoustics

Many scientists have made important contributions to the study of the soniferous behavior of fishes and how these fishes make sounds. It would take a whole book to introduce all these scientists. Instead I have chosen to focus on individuals that I feel have made especially significant contributions towards the early development of passive acoustics as a tool to study fishes and their habitat requirements.

The team of Marie Fish, William Mowbray and Paul Perkins

Marie Fish and William Mowbray (Courtesy URI Graduate School)

In search of new fish sounds, these scientists from the URI Marine Laboratory bioacoustics program prepare for a trip to 'audition' the noises sea creatures make. Mrs. Charles J. Fish, right, is head of the program. William H. Mowbray, left, is the chief electronics engineer, and Paul J. Perkins, center, is the oceanographer.

—URI Photo

Marie Fish and her husband Charles Fish both had long careers in marine biology. Together they set up the first marine laboratory at the University of Rhode Island in 1934, later known as the Narragansett Marine Laboratory and which has grown to become the prestigious Graduate School in Oceanography. Marie Fish was born in Paterson, N.J. and graduated from Smith College. She received her Ph.D. from the University of Rhode Island. She worked for the U.S.

Bureau of Fisheries and was Curator of Ichthyology at the Buffalo Museum of Science. After World War II she was asked by Admiral Nimitz to conduct hydrographic surveys of the Pacific. Thus began her long career in bioacoustics. She was awarded the Navy's Distinguished Public Service Award, the highest decoration for a civilian, in 1966. The importance of Marie Fish to passive acoustics is evident in the discussion of her work throughout this book, and culminated with the publication of her book "The Sounds of Fishes of the Northwest Atlantic" in 1970, which she co-authored with William Mowbray.

William (Bill) Mowbray was an engineer by training that worked with Marie Fish and other scientists at the Narragansett Marine Laboratory to develop the techniques and methods of recording fish sounds. His voice provides the narration to the fish sound library that was produced as a companion to their book, and which is still used by scientists today as a valuable reference library.

Paul Perkins was born in Boston, MA in 1923. He was a sonar technician for the Navy during the 1940's and was a Submarine Sonar Instructor at the Naval school in San Diego, CA. One of his early duties was to gather sea sounds to train sonar men for the Navy. He was the Chief Petty Officer in charge of the worlds first Sonar Information Center (later known as ASCAC). During twenty years of service he provided consultation to many scientists working on cetaceans (whales and dolphins), yellowfin tuna, shark sound studies, and others. After retiring from the Navy in 1962, Paul eventually joined Marie Fish and William Mowbray at the Narragansett Laboratory. He continued to work on the Bio-acoutics projects after Howard Winn took over the project from Marie Fish in 1967. Besides his extensive work with the underwater

sounds of fishes and invertebrates, Paul has made important contributions to our knowledge of cetacean sounds. Paul made one of the earliest recording of Humpback whale sounds aboard the submarine USS Bluegill in 1955. He also is credited with the first underwater recordings of sounds of Grey Whales (pulses and trains), Bottlenose Whales (pulses and whistles), Sperm Whales (whistles and squeals) and humpback whales (pulses and trains). Although retired, Paul continues to collect underwater sounds in Rhode Island waters and most recently published a paper on the striped cusk-eel in 2001 nearly 60 years after beginning his career in underwater sounds.

Charles Breder


Charles Breder

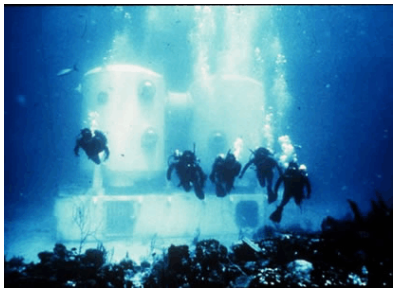
Charles Breder made significant contributions to fish biology over his long career, even though he did not have a formal college degree (later in life he was awarded an honorary Doctoral Degree from Newark University, now part of Rutgers University). He worked for the U.S. Bureau of Commercial Fisheries and then at the New York Aquarium before becoming Curator of Fishes at the American Museum of Natural History in New York in 1944. He published widely on the behavioral ecology of fishes, and is often still cited by scientists today. Charles Breder is considered a pioneer in passive acoustics applications to fisheries primarily because of his study of the "Seasonal and Diurnal Occurrences of Fish Sounds in a Small Florida Bay" that he published in 1968. In this study Breder recognizes the usefulness of passive acoustics as a tool to study the daily and

seasonal patterns of fish habitat use. He set hydrophones on the end of a pier and made systematic recordings throughout the year. He may have been the first scientist to use multiple hydrophones to pin-point the exact location of calling fish.

Thomas Bright and the Tektite Project

Peggy Lucas inside the Tektite Habitat observes diver Sylvia Earle (c.1970). From Exploring The Deep Frontier by Sylvia Earle and Al Giddings (Courtesy William Warmus).

One of the most extraordinary early passive acoustics studies was that carried out by Thomas Bright as part of the Tektite Project. Dr. Bright was a Professor at Texas A & M University who participated in the project In 1970. He collected extensive underwater acoustic and video observations on fish behavior. They reported on the sounds and behaviors of a number of important fishes, including groupers (Serranidae). Notably, they included examples of underwater sounds on a vinyl record published with the Tektite Report (Collette and Earle 1972). The study provides detailed spectrographic analysis and data on correlations between acoustic activity and specific behavior patterns and remains one of the most comprehensive studies of its type to date. To learn more about undersea habitats go to http://en.wikipedia.org/wiki/Underwater_habitat.



Tektite Project (Courtesy NOAA National Undersea Research Program)

Rountree, Listening to Fish

Grant Gilmore

Grant Gilmore listening to fish in the 1970's.

Grant Gilmore (right), Steven Van Meter (left), and Michael Lane (center), with the Passive Acoustic Monitoring System deployed on the Oculina Banks mission of the Islands in the Stream Ocean Expedition (Courtesy NOAA Ocean Explorer Program).

Grant currently serves as President and Senior Scientist of Estuarine, Coastal and Ocean Science, Inc. (ECOS) and has enjoyed an exciting and fulfilling career in marine biology. He is an expert in fish ecology and passive acoustic technology. Grant's pioneering work using passive acoustics to study the **habitat** needs and spawning behavior of the drum fishes has inspired many of his colleagues around the country to begin similar research projects. Grant received his undergraduate and masters degrees from the University of Western Florida and his Doctoral degree from the Florida Institute of Technology. He has worked for Harbor Branch Oceanographic Institution and NASA and has worked on marine documentary films for National Geographic, Audubon, and the Discovery Channel, among others.

Tony Hawkins

Tony Hawkins (Photo by Ken Ekstrom, MIT Sea Grant)

Anthony (Tony) Hawkins is currently Chairman of the North Sea Commission Fisheries Partnership and also a Director and Rapporteur of the new North Sea Regional

Advisory Council, which advises the European Commission on the management of North Sea Fisheries. He is an Honorary Professor at the University of Aberdeen and Managing Director of Loughine Limited, an environmental consultancy. He is a specialist in fish behavior and is researching both fish sound production and the impact of underwater sound upon fish. Tony has been studying the sounds produced by important fishery species in European waters since the 1950's and is the worlds expert on sound production and behavior of fishes in the family Gadidae.

Phil Lobel

Phil Lobel using advanced technology to study the soniferous behavior of fishes on coral reefs. (Reprinted with permission from Marine Technology Society Journal 35(2):19-28).

Dr. Phil Lobel is a Professor at Boston University who has pioneered the use of advanced technologies for the *in situ* (that means "in the field under natural conditions") behavior of fishes. He has studied coral reef fishes all over the world. Dr. Lobel has also mentored a number of students in the field, including Dr. David Mann. Phil and his student David Mann developed the first self-contained device for recording underwater sounds at specific locations on coral reefs. Divers would place the device on a coral reef next to a fish nest and then record sounds for several days. They named this device the "spawn-o-meter". More recently Phil has been using advanced rebreather diving technology in his studies. The rebreather device recirculates the divers breath and does not release a noisy burst of bubbles when the diver

exhales like normal SCUBA does. He finds that it is much easier to study fish with this gear as they are often frightened by regular SCUBA.

James Moulton

James Moulton was a professor of Ichthyology at Bowdoin College in Maine. His many studies included early attempts at playback experiments with searobins and descriptions of soniferous fishes of the Bimini Islands during the 1950s. He was one of the first scientists to suggest that listening to fish sounds can be a useful way to study fish distributions.

A new frontier

Rodney Rountree deploying an acoustic array on an ROV from the R/V Connecticut in the Stellwagen Bank National Marine Sanctuary.

Many exciting developments are being made in passive acoustics that promise a bold new frontier in marine science. Scientists are beginning to use passive acoustics as a tool for exploration. On land, we don't think anything of using sound to help us find animals. For example, herpetologists (scientists that study reptiles and amphibians) routinely search for frogs by listening for their chorus sounds. Not only can they find frogs that way, but they can also map out frog spawning areas that way, too. Similarly, ornithologists (scientists that study birds) routinely conduct bird counts by listening for bird calls. It is common practice to confirm the presence of a bird species simply by its sound, even if the bird itself is never seen. Well, ichthyologists (scientists that study fish) are just now beginning to listen to fish for the same reasons. For example, I mentioned earlier how the striped cusk-eel was found in an area where no one thought it occurred because its sounds were heard. Soon we expect scientists from all over the world will begin conducting studies like the ones you've read about in this book. We are already finding more and more new underwater sounds and soon we will begin to learn more about the animals that make them. Now that's exciting!

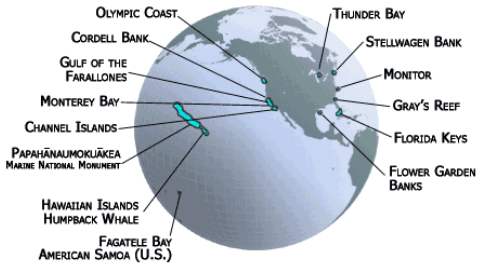
A deep-sea fish off of South Carolina (Courtesy Paula Keener-Chavis and Andy Shepard).

One promising new area of exploration is in the deep sea, where some scientists believe many species may be soniferous because of the absence of light. That's because without light visual communication is difficult. For example, without light you can't see a predator coming closer, you can't see a mate nearby, and you can't see food, but you can still hear. So if a fish makes a sound, then maybe its mate can find it, or maybe if it makes a scary noise it can scare away a predator. Recently David Mann and Susan Jasper (Naval Undersea Warfare Center) recorded sounds they think were produced by a fish in deep water in the Carribean sea. And as I write this book, Cliff Goudey, Francis Juanes and I are preparing to put hydrophones and cameras in deep waters off the coast of Massachusetts. Imagine using sounds to help explore the deep ocean! Instead of going down in submarines, or sending down remotely operated vehicles (ROVs), and just hoping you will find a fish, you can listen for their sounds and follow the sound to the fish!

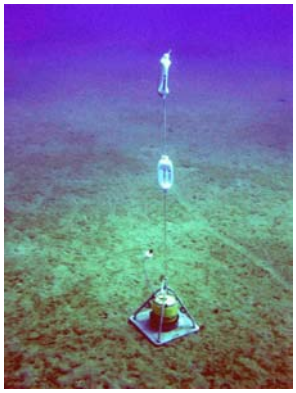
Cliff Goudey demonstrating a special deep water acoustic recorder to a commercial fisherman. (Rodney Rountree)

In other areas, Cliff Goudey and I have been working with Cathy Sakas of the Grays Reef

National Marine Sanctuary, which is located off the coast of Georgia, on a new program to put hydrophones in all 13 Marine Sanctuaries in the United States. We believe that one day scientists will have networks of "listening stations" set out all over the oceans to help study fish and other marine animals better than ever before. When several listening stations are put close together, scientists can use computers to actually track the locations of the fish that are making sounds. In that way, we can map where the fish are when they call and learn all kinds of things about their behavior and activities. And can you imagine if the listening stations also have cameras, and maybe even little submarines called "Autonomous Underwater Vehicles" (AUVs), that can record underwater video of the fish? Someday, I hope that people all over the world will be able to go to their computer, log onto the internet and view underwater video of fish in all kinds of habitats and listen to their sounds. Wouldn't that be cool!



Location of the National Marine Sanctuaries (Courtesy NOAA)



Acoustic recorder deployed in the Humpback Whale National Marine Sanctuary off Hawaii.

Glossary

Acoustics - the science of sound and sound technology.

Aristotle - a famous Greek scholar who lived over 2000 years ago. He was the teacher of the even more famous Greek ruler Alexander the Great. Aristotle wrote about many things, but he especially loved to study animals and plants. For hundreds of years people have studied his teachings.

Bass, Andy - A Professor at Cornell University who has conducted extensive research on the soniferous behavior of fishes, especially of the midshipman. Dr. Bass studies the fish brain and nervous system to learn how fish communicate.

Andy Bass (courtesy Cornell University)

Batrachoididae - A family of fishes containing the toadfish and midshipman. Their eyes are on top of their wide heads and they have very big mouths. Most live on the bottom of the ocean where they hide in the sand, mud or rocks waiting for prey to swim close. If something does swim too close, the toadfish just opens it big mouth and swallows it whole! There are about 73 kinds of toadfish and midshipman that live mostly in tropical and subtropical waters. The name for the family comes from the Greek word for frog (batrachos) because the fish are typically squat and fat and frog-like in appearance.

Byssal threads - Mussels often live in habitats with lots of strong currents or waves and they need strong anchors to keep from getting washed away. So they make strong threads

called byssal threads that they attach to their shell on one end and to a rock on the other end. Clumps of these threads keep the mussels anchored securely to a rock even when the waves pound on them.

Carangidae - A family of fish known as the jacks. There are about 140 species world wide. Many are fast swimming schooling species popular in public aquaria.

Courtship - what a fish does (its behavior) before and during spawning (laying eggs or having babies). Often a male fish will make sounds and/or visual displays to try and attract a female. Visual displays are things like flashing fins or making sudden jerking movements. Sometimes males make nests, but other times eggs are just spread out in the open water so the eggs can drift in the currents.

Cousteau, Jacques-Yves - A French scientist that together with Frenchmen Emile Gagnan invented the first SCUBA gear in 1943. He is most famous as an undersea diver who traveled the world aboard his ship the *Calypso* to explore undersea life. He made many movies of undersea life so that millions of people around the world could see the wonderful world under the sea. He has also written many books about underwater life and his experiences as a diver. If you would like to learn more about Cousteau, ask your librarian about his books and books about him.

Fine, Michael - Dr. Michael Fine is a Professor at Virginia Commonwealth University who studies how fish make sounds. He has conducted extensive research on the oyster toadfish, catfishes and drum fishes. Dr. Fine's research focuses on Neurobiology and behavior of marine

Michael Fine (Courtesy Virginia Commonwealth University)

fishes. He is especially interested in studying mechanisms of sound production, and how the swim bladder and sonic muscles function.

Fish, Marie - (1901-1989) an oceanographer and marine biologist that pioneered the study of underwater sounds at the University of Rhode Island. She helped establish the Narragansett Marine Laboratory at URI (later to become the Graduate School of Oceanography) and recorded the sounds of over 300 species of marine animals. She made important contributions to national defense in her work for the US Navy.

Gadidae - A family of fishes that contains cod, haddock and other cod-like fishes that are among the most important fishery species in the world. There are over 50 different species. The family name comes from the ancient Latin name for cod (Latin is the language that was spoken by the ancient Romans).

Gas bladder - see swim bladder.

Gilmore, Grant - An expert in fish ecology and passive acoustics. Dr. Gilmore has pioneered the use of passive acoustics to study fish spawning habitats in estuaries and coastal marine habitats in the Southeastern United States. He has worked for the Harbor Branch Institution and NASA, and has consulted on many documentary films for National Geographic, Audubon and the Discovery Channel.

Grant Gilmore (Ken Ekstrom)


Cliff Goudey

Goudey, Cliff - The director for the Center for Fisheries Engineering Research at the Massachusetts Institute of Technology Sea Grant College Program. He works closely with fishermen and scientists to develop new technologies and new applications for existing technology for fisheries and marine science.

Habitat - place where fish live. Usually we describe a habitat based on what lives there, or what kind of dirt is found there. For example, you may have heard about habitats such as coral reefs or seagrass beds, or kelp forests. If not, I encourage you to look up information on them in your library or on the internet.

Hawkins, Tony - Dr. Anthony Hawkins has had many titles in his long career and is currently Managing Director of Loughine Limited, an environmental consultancy. He has worked on fish sound production for over four decades and has pioneered the use of passive acoustics in fisheries science in European waters. He has studied many fish, but is perhaps best known for his extensive work with the Gadid fishes like Atlantic cod and haddock.

Hydrophone - an underwater microphone used for listening to underwater sounds.

Ichthyologist - A scientist who studies fishes. The word comes from the ancient Greek word for fish (ichthos) and "to study" (logos).

Juanes, Francis - A professor at the University of Massachusetts at Amherst. Dr. Juanes' area of research is ecology, evolution and behavior of fishes and benthic crustaceans. Together with Rodney Rountree and Cliff Goudey, he has worked to pioneer the use of passive acoustics for fisheries and the exploration of the seas.

Francis Juanes (Courtesy UMass Amherst)

Lobel, Phil - Dr. Phil Lobel is a Professor at Boston University. His laboratory studies the reproductive ecology and behavior of fishes in many tropical areas including coral reefs and African lakes. The goal of his bioacoustics research is to determine which fishes produce species-specific sounds during courtship. Dr. Lobel has mentored many students and has pioneered the use of advanced technologies to study fish soniferous behavior.

Phil Lobel (Courtesy Ken Ekstrom)

Luczkovich, Joe - Dr. Joe Luczkovich is a Professor at East Carolina University who studies the behavior and ecology of fishes. Bioacoustics is one of the major focal points of his laboratory. He and his colleague Mark Sprague, a physics professor at ECU, have pioneered the use of large arrays of small passive acoustics recorders to map the spawning locations of estuarine fishes. To find out more about Joe's work, go to his web page at:

Joe Luczkovich (ECU)

Rountree, Listening to Fish

http://personal.ecu.edu/luczkovichj/

Mann, David - Dr. David Mann is a Professor of Ichthyology at the University of South Florida. His laboratory studies marine bioacoustics with a focus on hearing and sound production in fishes. He studies how fish make sounds and how they hear sounds. But Dave's laboratory is also pioneering the development of advanced technologies to aid scientists in the study of fish sounds. He has established an ocean acoustic monitoring system in Sarasota Bay and Charlotte Harbor Florida using hardwired hydrophones and autonomous dataloggers. The main goals of this project are to determine the timing and place of spawning of sound-producing fishes, to study interactions between cetaceans and sound-producing fishes, and to identify patterns of boat noise. He is also involved in studies of the hearing abilities of manatees and other marine mammals. To learn more about Dr. Mann's research go to his web page at: http://www.marine.usf.edu/bio/fishlab/

David Mann (courtesy USF)

Marine Biological Laboratory (MBL) - The MBL is the largest marine research institution in the world with over 1000 scientists and students. It was founded in 1888 in Woods Hole, Massachusetts to study marine biology. Some of the world's most famous scientists have worked or studied at MBL.

Mowbray, William - Dr. Mowbray was an electric engineer at URI who worked together with Marie Fish and Paul Perkins to develop an extensive archive of underwater sounds. Their important work laid the foundations for the work of future

William Mowbray recording underwater sounds from a specially equipped van (Courtesy Friends of the URI Graduate School of Oceanography).

scientists interested in underwater sounds and their sources.

Mussels - No, these are not "muscles;" they are a type of mollusk with two shells, similar to clams and oysters. Mussels are a popular dish in many restaurants. Mussels usually live in groups of dozens to thousands of individuals. Naturally, they live attached to rocks or other shells, especially on rocky shores, but now you can often find them living on pier pilings and seawalls.

Ophididae - the cusk-eel family of fishes that contains over 218 species. They are not really eels, but are often long and skinny like an eel. Not much is known about these fishes, but they include many very deep water fishes, including one kind that was found in water deeper than any other fish (over 8,000 meters deep). The Family is named from the ancient Greek word for snake (ophidion).

Passive acoustics - the science of listening to underwater sounds.

Sciaenidae - the family of fishes that contains the croakers and drums and has over 270 species worldwide. Many are important food fishes and are popular as gamefish. The family name comes from the ancient Greek word for perch (sciaena) which is a common freshwater fish in North America and Europe.

Scientific name - Scientists name animals and plants in a special way. Each kind of animal or plant is called a species and it is given a two part name. The first part of the name is called the "genus" and the second part is called the "species" or "specific" part. For example, the striped cusk-eel's scientific name is "*Ophidion marginatum*." *Ophidion* is the genus and *marginatum* is the specific part. Together the two parts of the name define

a species. Species that are very closely related are always given the same genus, but a different specific name. For example, *Ophidion robinsi* is the scientific name of another kind of cusk-eel that is very similar to the striped cusk-eel. Species that are kind of similar, but not similar enough to be put into the same genus, are put into a "family" of fishes. So all the different kinds of cusk-eels are put into the family Ophidiidae. The scientific name is also important, because it helps scientists from all over the world understand each other when they talk to each other about a fish species. Common names like "striped cusk-eel" can change depending on where you live and what language you speak. But the scientific name does not change. Another important thing about the scientific name is that it tells the scientists something about the species, so that even someone who has never seen the striped cusk-eel will know something about it just by knowing what family it belongs in and what its scientific name means. For example, *Ophidion marginatum* means "snake-like with a margin." That tells scientists that the striped cusk-eel is long and skinny like a snake, and has some kind of colored marking along the margin of its fins. Sometimes scientists also name fish after other scientists. For example, the newly discovered cusk-eel species *Ophidion robinsi* was named after Dr. Robins who has studied cusk-eels for many years.

Snapping shrimp - small shrimp-like animals also known as "pistol shrimp" that make loud snapping sounds with their claws. If you ever go down to a salt-water creek or estuary in the southeastern and Gulf coast states in the US you might hear the snap, crackle and popping sounds they make, especially at low tide.

Sonic muscles - special muscles that push, pull or rub against the swim bladder to make sounds (see "swim bladder" for more information).

Soniferous - vocal or sound-making; capable of making sounds.

Spawn - when a fish either lays eggs or has babies.

Species - a scientific term meaning "kind" or "type". A fish species means a particular type of fish like a haddock.

Stridulation - making sound by rubbing two body parts together. Often one or both body parts have sharp ridges or spines that scrape against each other to make a squeaky sound. You have probably heard the stridulation sounds of crickets, cycads or other insects. Two common ways that fish make stridulation sounds are by rubbing fin spines together or grinding their teeth.

Swim bladder - a special organ inside a fish that is basically an air-filled sac, kind of like a balloon. One of its uses is for controlling buoyancy (whether the fish sinks, floats, or stays in the same place in the water). If the fish inflates its swim bladder it will rise up toward the surface, and if it deflates the swim bladder it will sink towards the bottom. SCUBA divers use buoyancy control devices (BCs) to do the same thing. Because the swim bladder is filled with air, it is also used in sound production. Try pinching a wet, inflated balloon several times real fast. Now try rubbing it with your thumb. What happens? You're right! You just made some sounds very similar to some of the fish sounds in this book! Cool!

Tektite Project - NASA, the US Navy, the U.S. Department of the Interior and General Electric

Corporation launched the Tektite project in 1969 as one of the first undersea habitats. During the project scientists lived in an underwater habitat located in 15 m of water in Lameshur Bay, St. John, US Virgin Islands. In 1969 four Aquanauts Ed Clifton, Conrad Mahnken, Richard Waller and John Van Derwalker lived 50 ft below the surface for 58 days as they conducted extensive experiments and were constantly monitored (just like space astronauts). In 1970 many scientists joined the team to study all aspects of marine life. To learn more about undersea habitats go to http://en.wikipedia.org/wiki/Underwater_habitat.

Vocal behavior - making sounds and what the fish does when it makes sounds (see "soniferous").

Woods Hole Laboratory of the National Marine Fisheries Service - America's first government conservation program, the United States Commission of Fish and Fisheries, was started in 1871. Spencer Baird was hired by President Grant (the famous General from the Civil War) as the first Commissioner of Fisheries. The agency has changed names several times over the years and is now known as NOAA National Marine Fisheries Service (or NMFS for short). NOAA stands for National Oceanographic and Atmospheric Administration. The NMFS studies marine fish and how natural events, pollution and fishing affects them, and makes rules and regulations on how people can fish for them. Spencer Baird began his studies in Woods Hole, Massachusetts shortly after being hired and the first laboratory was built there in 1885. It was because of the work of Baird and the NMFS that MBL and WHOI were later built in Woods Hole and

the town grew to become a world famous center for marine research.

Woods Hole Oceanographic Institute (or WHOI for short) - WHOI was started in 1930 to study oceanography. Oceanography is the science of the sea. Scientists at WHOI use advanced technology (tools and machines) to study the oceans and the life in it. Oceanographers travel all over the world and sometimes travel deep beneath the ocean's surface in submarines like Alvin to conduct their research.

The author, Rodney Rountree, listening to fish in the Waquoit Bay National Estuarine Research Reserve on Cape Cod, Massachusetts.