Listening to Fish

Passive Acoustic Applications in Marine Fisheries

SEA GRANT DIGITAL OCEANS

Building on work pioneered by Sea Grant to yield data for sustainable ocean resources

Listening to Fish:
An International Workshop on the Applications of Passive Acoustics to Fisheries

Front cover: cod

Credit: Tony Hawkins, University of Aberdeen

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The Challenge

Scott Holt on pier listening to fish

Credit: Scott Holt, University of Texas at Austin

Passive acoustic technologies are those technologies that enable us to listen to and record ambient underwater sounds. Such technologies have existed for decades; however, a major initiative to develop and promote their use in fisheries applications and as an important new tool for the census and exploration of marine life is now needed. Given the significant advancement in underwater technologies, passive acoustic research promises to be an important new field in fisheries and related areas/disciplines. The ability to listen to fish and other marine life allows scientists to identify, record and study underwater animals, even in the absence of visual information. Coupling passive acoustics with conventional visual monitoring and sampling techniques provides a powerful new approach to undersea research. The Sea Grant College Program has recognized the great potential of passive acoustics for fisheries and related fields, and has taken a leadership role in supporting the development of innovative new research programs using this approach.

The F/V Seeker, Gloucester, MA

Credit: Madeleine Hall-Arber, MIT Sea Grant College Program

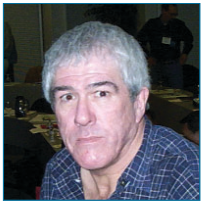
Bringing Scientists Together

On April 8-10, 2002, MIT Sea Grant hosted an international workshop on the application of passive acoustics in fisheries.

Conference luncheon

The workshop was held at the Brooks Center, part of MIT's Endicott House facilities in Dedham, Massachusetts. At the workshop, more than 40 North American and European experts from fisheries, fish biology, acoustics, signal processing, underwater technology, and related fields shared research results, knowledge and ideas. Fisheries biologists gained valuable insight through an exchange of information with scientists experienced in the use of passive acoustics in marine mammal studies. Participants were also able to discuss ideas and experiences in hardware and software technologies. Previously, many of these scientists had been working in relative isolation with little interaction with colleagues in North America and overseas. The workshop has already fostered new domestic and international collaborations in the field. In short, the workshop confirmed the great potential of passive acoustics as a research tool for fisheries.

Finally, the workshop allowed extensive discussion of future research priorities for passive acoustics. Some of the most important research initiatives identified by the workshop participants were: 1) developing a national database of historic underwater sound archives; 2) establishing a national/international reference library of fish sounds, which would be guided by an international panel of scientists; 3) establishing an international research and training center for passive acoustic applications for fisheries and marine census; 4) establishing regional "listening-posts" to monitor fish sounds and promote passive acoustic research; and 5) actively promoting the technology through publications of the workshop proceedings and related articles.



Conference participants (from top to bottom): Joseph Blue, Tony Hawkins, Phil Lobel, Judith Fudge.

Credit: Cliff Goudey, MIT Sea Grant

Credit: Scott Holt, University of Texas at Austin

Workshop Sponsors

The workshop and resulting publications were sponsored by:

- MIT Sea Grant College Program
- Office of Naval Research (ONR Code 342, Marine Mammal S&T Program)
- Northeast-Great Lakes Center of the National Undersea Research Program

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- Connecticut Sea Grant Program
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- Louisiana Sea Grant Program
- North Carolina Sea Grant Program
- South Carolina Sea Grant Consortium
- Texas Sea Grant Program
- Woods Hole Sea Grant Program

The Promise

Fish are difficult to see and study in the ocean. While scuba techniques can help in shallow waters and a range of active acoustic and optical techniques can assist in deep water, we are still largely ignorant of the distribution and behavior of the great majority of marine fish. Possibly one of the greatest challenges to researchers attempting to study the behavioral ecology of fishes is finding the fish in the first place. Any tool that can help scientists locate fish is therefore valuable. Fortunately, many fish use sound to overcome the problem of living in an environment with limited light and visibility. Fishes produce sounds to communicate with one another while they are mating or being aggressive, and they also make noises associated with feeding and swimming. Over 800 species of fishes from 109 families worldwide are known to be vocal. Of these, more than 150 species are found in the northwest Atlantic. Among these vocal fishes are some of the most abundant and important commercial fish species, including cod, haddock, and the drum fishes.

Fishing boats docked at Gloucester Harbor, Gloucester, MA

Credit: Madeleine Hall-Arber, MIT Sea Grant

Passive acoustic techniques can be used to locate individuals and concentrations of particular species, especially during their vulnerable spawning stage. This in turn allows spawning habitat to be identified, mapped, and protected. Passive acoustics can allow the numbers of fish to be assessed and can be used to gain a better understanding of fish behavior, including migrations. Passive acoustics can also be used to monitor sources of noise pollution and to study the impact of human activities on marine communities. Anthropogenic sources of noise pollution include vessel activity, seismic surveys, sonars, oil and gas drilling, and military activities. These all have an unknown but potentially important impact on marine fish.

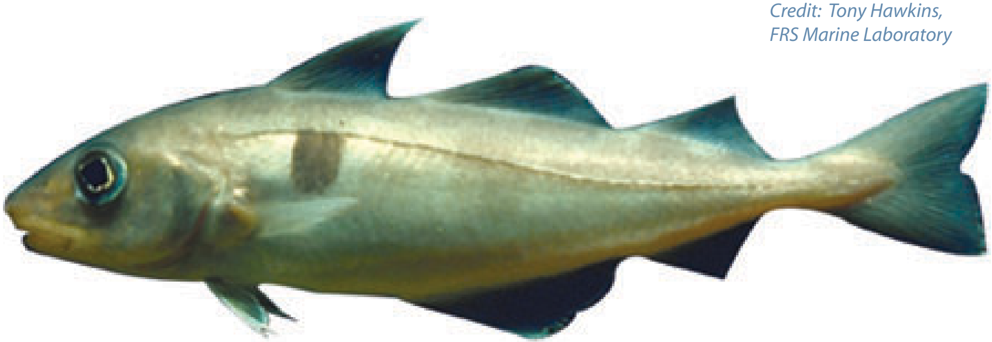
The workshop participants believe that passive acoustic technologies hold special promise and will become important tools in the coming years. However, these techniques have been largely ignored in the northwest Atlantic for the study of fisheries resources. Passive acoustics is also amenable to cooperative research with commercial fishermen, who can bring their own knowledge to such studies.

Applications to Fisheries

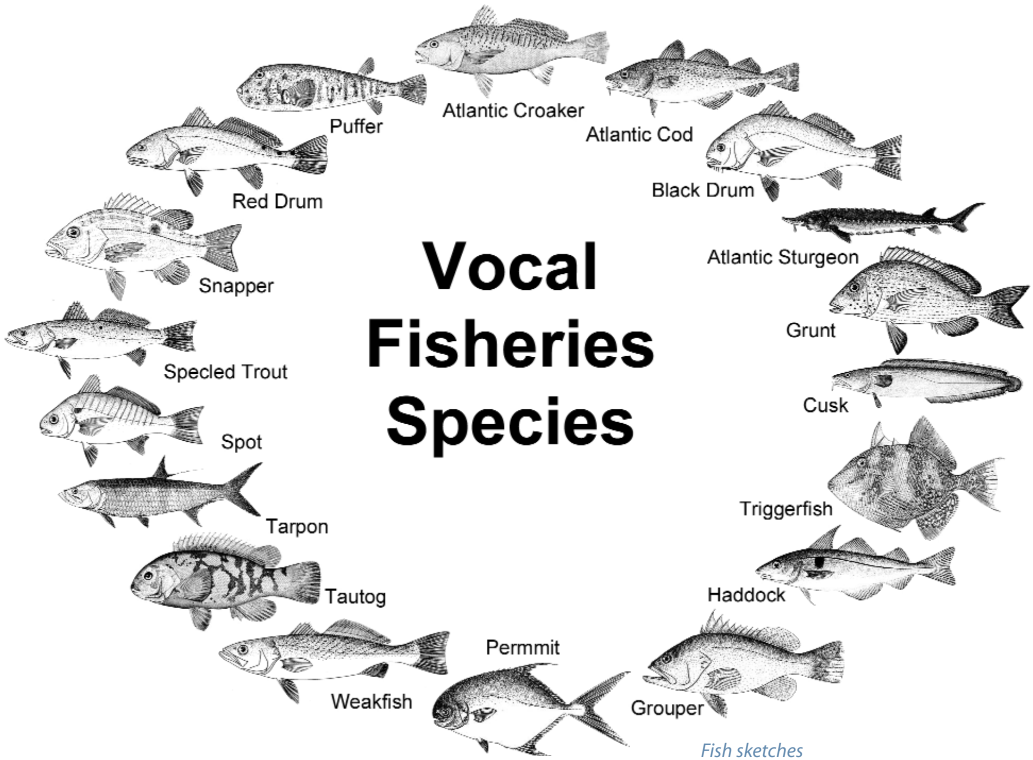
Using hydrophones, marine ecologists and fishery biologists have been able to listen to the sounds fish produce and identify species-specific and even individual-specific signatures using signal processing and spectral analysis computer algorithms. Often, as in the case of the drum family *Sciaenidae*, these sounds are very loud and dominate the acoustic environment where they occur, so much so that they interfere with military and petroleum prospecting operations that involve acoustic monitoring. In other situations, such as with damselfishes on coral reefs, the sounds are not loud and are detectable only with specialized techniques.

Haddock

Credit: Tony Hawkins, FRS Marine Laboratory



Examples of some vocal fish species important to North American Fisheries:

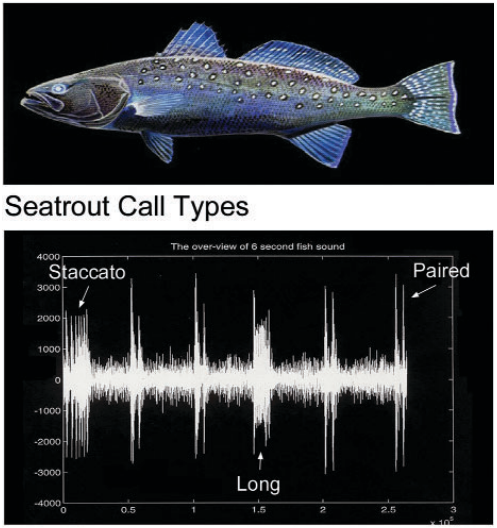


Fish sketches courtesy of NOAA/NMFS Northeast Fisheries Science Center

To identify the species of fish producing a sound, one first must do "sound-truthing." There are two principal ways this has been accomplished: 1) captive fish recordings and 2) *in situ* (i.e., in the field under natural conditions) recordings. However, acoustic complication in a tank or aquarium, combined with unnatural behavior and sound production, makes the first approach problematic. Equally severe problems exist with *in situ* recording because of the difficulty in matching sounds to species and behaviors. Knowledge of sound source levels is important for calculating the detection limits of hydrophones. Precise measurement of sound sources requires knowledge of the location of the fish and the hydrophone's characteristics. Biologists have been able to link the aggressive and spawning behavior of fishes to their sound production using a combination of *in situ* and tank studies. For example, sounds produced by haddock during

Joe Luczkovich monitoring fish sounds in laboratory

Credit: Joe Luczkovich, East Carolina University



Seatrout and its call types spectrogram

Credit: R. Grant Gilmore, Jr., Kennedy Space Center

courtship and mating have been recorded and analyzed in this manner. Once the association of sounds to specific species and behaviors has been established, passive acoustics provides a rapid method of establishing the spawning component of essential fish habitat (EFH).

Investigators often have used onomatopoeic terms such as "grunts," "knocks," "snaps," "pops," "staccato," "drumming," "humming," "rumbles," "percolating," "purring," etc., to describe fish sounds. A standardization of these sound descriptions is needed to allow rapid communication between biologists and other observers. A less convenient but more robust way of precisely reporting such sounds is to make a spectrograph or "voice print" of the sound recording. Similar tools can be used to identify an individual fish as a method of noninvasive tagging.

The Benefits of Passive Acoustics

- The technique provides a non-invasive, non-destructive census of marine life.
- It works at night without bias (versus video and other techniques that require lights).
- It can provide continuous monitoring of fishes.
- It provides remote census capabilities.
- It can determine the daily and seasonal activity patterns of fishes, including determination of discrete daily spawning times.
- It provides a better foundation for the management of exploited species by mapping their distribution and pinpointing their spawning grounds.
- It offers a better understanding of the habitat preferences of key fish species (e.g., essential fish habitat assessment in the U.S.), providing a better focus for their conservation.
- It establishes baselines for the abundance and distribution of key fish species, allowing examination of the effects of future environmental change.
- It can help us obtain a wider knowledge of the behavior of those fish that cannot readily be studied by any other method.
- It can be used to monitor environmental noise and determine its source.
- It can be used to examine the impact of anthropogenic noise on fish, especially on spawning behaviors.
- Networks of listening posts can provide synoptic data on the occurrence of fishes and spawning activities on local, regional, national and global scales.

Passive acoustic studies using relatively simple techniques have been successful in locating concentrations of important fish species, opening the way for further, more detailed studies of their behavior, distribution and habitat use. Many significant strides were reported at the workshop in the application of passive acoustics to fisheries.

R. Grant Gilmore, Jr. sampling fish sounds in Florida estuary

Credit: R. Grant Gilmore, Jr., Kennedy Space Center

Estuaries

- Passive acoustic applications to fisheries were pioneered with studies of *sciaenid* fishes (the drum fishes) in estuaries in the southeastern United States by scientists at the Harbor Branch Oceanographic Institution. These studies have expanded into other programs, including studies at East Carolina University, Louisiana State University, the University of Texas at Austin, the University of South Florida, Washington College (MD), the Virginia Commonwealth University, and the South Carolina Marine Research Institute. This research has demonstrated the usefulness of passive acoustics as a tool for identifying essential fish habitat and for providing fisheries managers with information on *sciaenid* reproductive biology.

- Researchers have more recently begun conducting passive acoustic surveys in estuaries of the northeastern United States. Scientists at the School for Marine Science and Technology at the University of Massachusetts Dartmouth and the University of Massachusetts at Amherst have begun a survey of soniferous fishes of Massachusetts. One early finding of this program was the discovery that the striped cusk-eel, *Ophidion marginatum*, is widely distributed in state waters, despite previously being thought to range only from New York to Florida. This study has demonstrated that even a basic approach to passive acoustics can contribute significantly to the census of marine life.

Striped cusk-eel

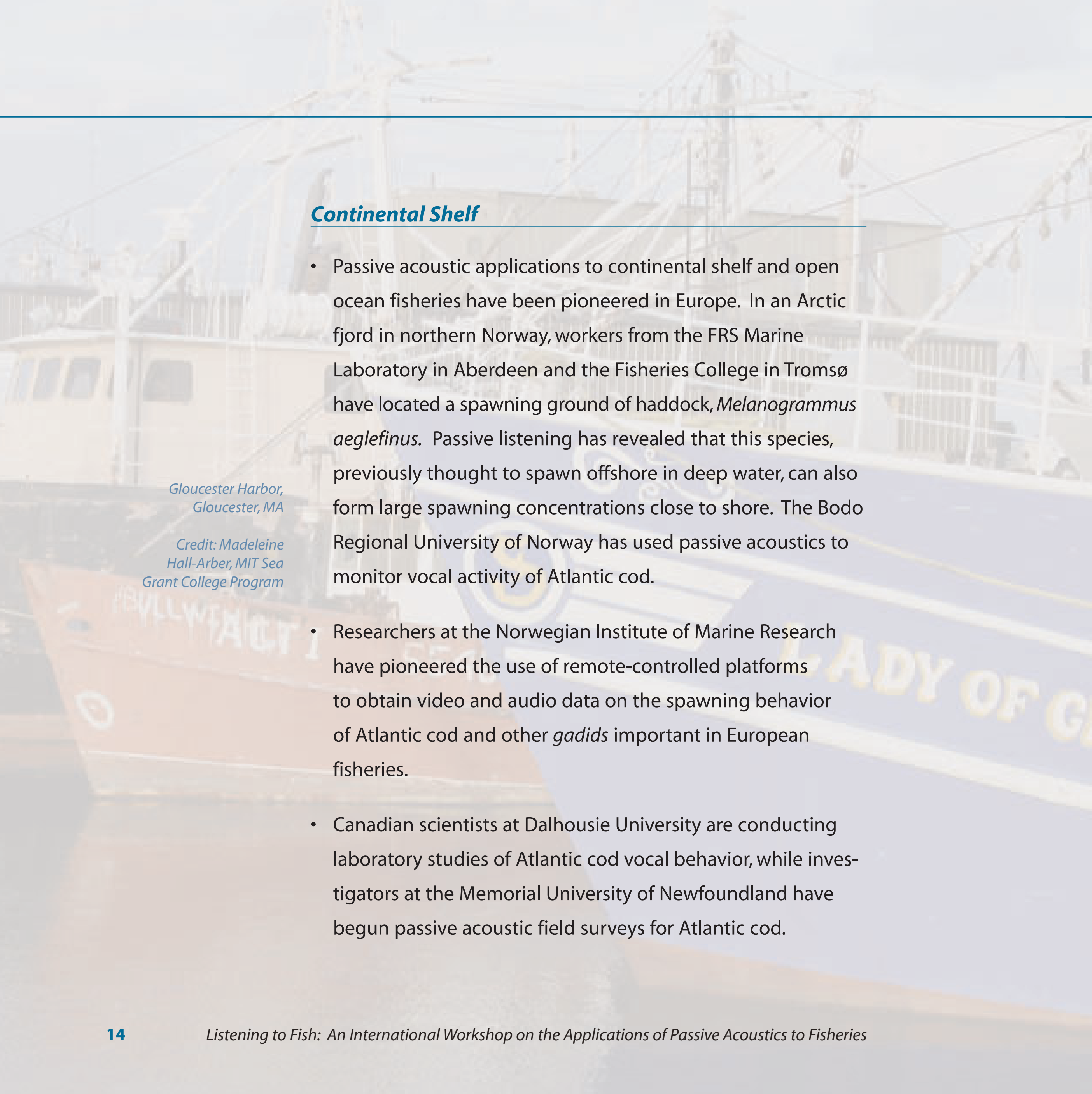
Credit:
Rodney Rountree,
UMass Dartmouth

Continental Shelf

- Passive acoustic applications to continental shelf and open ocean fisheries have been pioneered in Europe. In an Arctic fjord in northern Norway, workers from the FRS Marine Laboratory in Aberdeen and the Fisheries College in Tromsø have located a spawning ground of haddock, *Melanogrammus aeglefinus.* Passive listening has revealed that this species, previously thought to spawn offshore in deep water, can also form large spawning concentrations close to shore. The Bodo Regional University of Norway has used passive acoustics to monitor vocal activity of Atlantic cod.

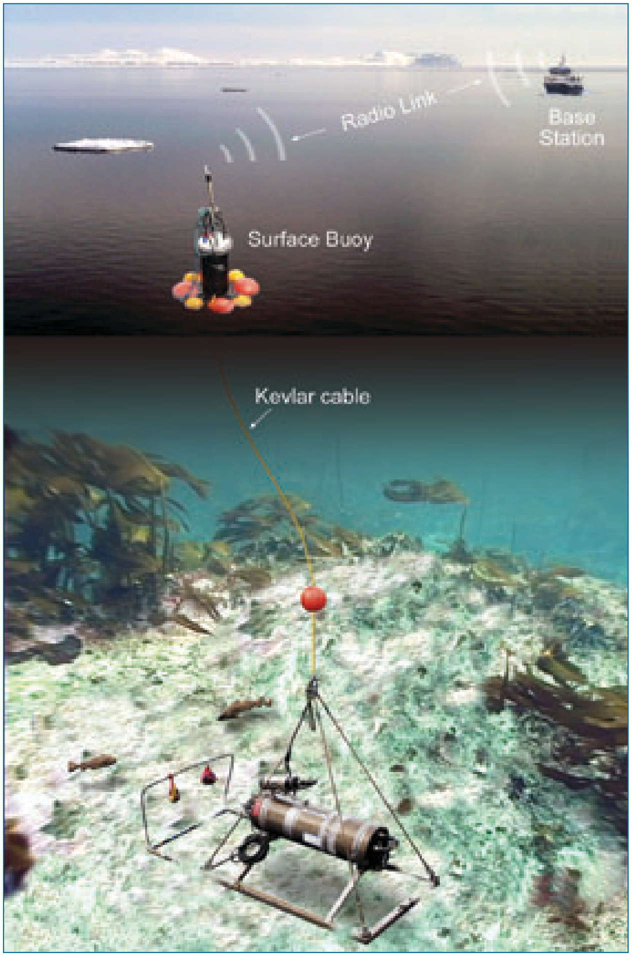
- Researchers at the Norwegian Institute of Marine Research have pioneered the use of remote-controlled platforms to obtain video and audio data on the spawning behavior of Atlantic cod and other *gadids* important in European fisheries.

- Canadian scientists at Dalhousie University are conducting laboratory studies of Atlantic cod vocal behavior, while investigators at the Memorial University of Newfoundland have begun passive acoustic field surveys for Atlantic cod.



Gloucester Harbor, Gloucester, MA

Credit: Madeleine Hall-Arber, MIT Sea Grant College Program



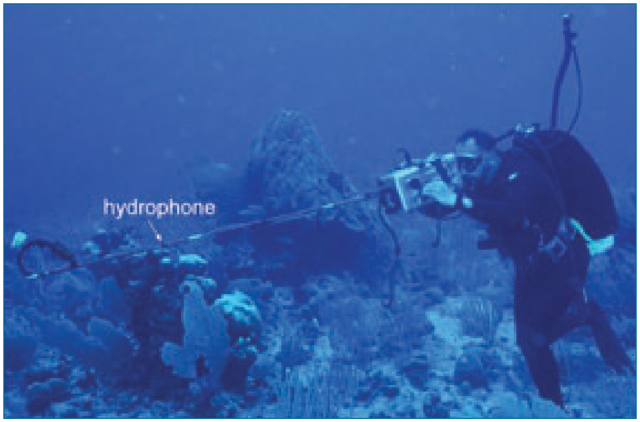
Remote-controlled instrument platform

Credit: Jan Tore Ovredal, Institute of Marine Research, Bergen, Norway. Adapted for use in this publication.

• Passive acoustics is being explored as a tool to conduct a census of marine fishes on the continental shelf of the United States. In one study at the University of Texas at Austin, a towed hydrophone array is being used to identify spawning sites of red drum in the western Gulf of Mexico. In a study at UMass Dartmouth's School for Marine Science and Technology (SMAST), passive acoustics is being used to catalogue soniferous fishes in the Stellwagen Bank National Marine Sanctuary. SMAST and MIT Sea Grant Center for Fisheries Engineering Research (CFER) researchers have also begun using autonomous archival sound recorders to monitor Atlantic cod and haddock sounds in the Gulf of Maine and on Georges Bank.

High-tech scuba sampling of vocal fish

Reprinted from: Lobel P. S. 2001. Fish bioacoustics and behavior: passive acoustic detection and the application of a closed-circuit rebreather for field study. Marine Technology Society Journal 35(2)19-28.



Coral Reefs

- Although scientists have long studied the vocal behavior of coral reef fishes, researchers at the Boston University Marine Program in Woods Hole, Massachusetts have made significant advances in adapting new technologies to this field, including the development of the "spawn-o-meter," designed to study spatial and temporal patterns in fish reproduction. Another advancement is the use of rebreathers in scuba studies of fish behavior to avoid adverse acoustic effects of standard scuba gear. More recently, scientists at East Carolina University and the National Oceanographic and Atmospheric Administration (NOAA) Honolulu Fisheries Laboratory have begun studies of vocal fishes within the Hawaiian Island Reef system.

A variety of fish in a healthy reef ecosystem

Credit: James P. McVey, NOAA Sea Grant

New Technology

Studies described at the workshop have pushed technology to new levels that will allow researchers to expand the frontiers of fisheries science and ocean exploration:

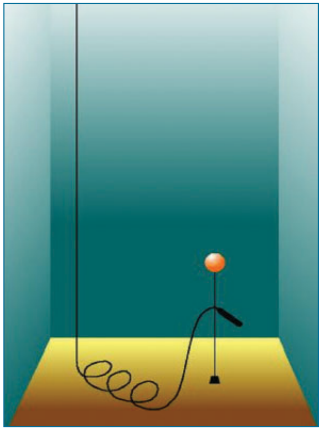
Joe Luczkovich with data logger sonobuoy

Credit: Joe Luczkovich, East Carolina University

- Researchers are beginning to look towards existing acoustic arrays maintained by the Navy and other agencies for applications to fishes.
- The potential for combining hydrophone arrays with other underwater census technologies, including remotely operated vehicles (ROVs), underwater video, advanced scuba technologies, and active acoustics is being explored.
- Advances are being made in the development of modeling tools and software for tracking vocal fish and identifying individual fish.
- New technologies for detecting and recording underwater sounds are rapidly evolving.
- Historic archives of fish sounds are being assembled and rescued from deterioration and will be made available to researchers and the public through the Internet. This is an important step toward greater use of passive acoustics in fisheries science and related fields.

A Primer on Techniques

The success and development of fish bioacoustics depend on high-quality recording systems and analysis software. It is especially important that the technology be matched to the questions being asked. For most questions, the needed technology exists for advancing fish bioacoustics, and the main impediment is insufficient knowledge about using the technology.



Hydrophone in water

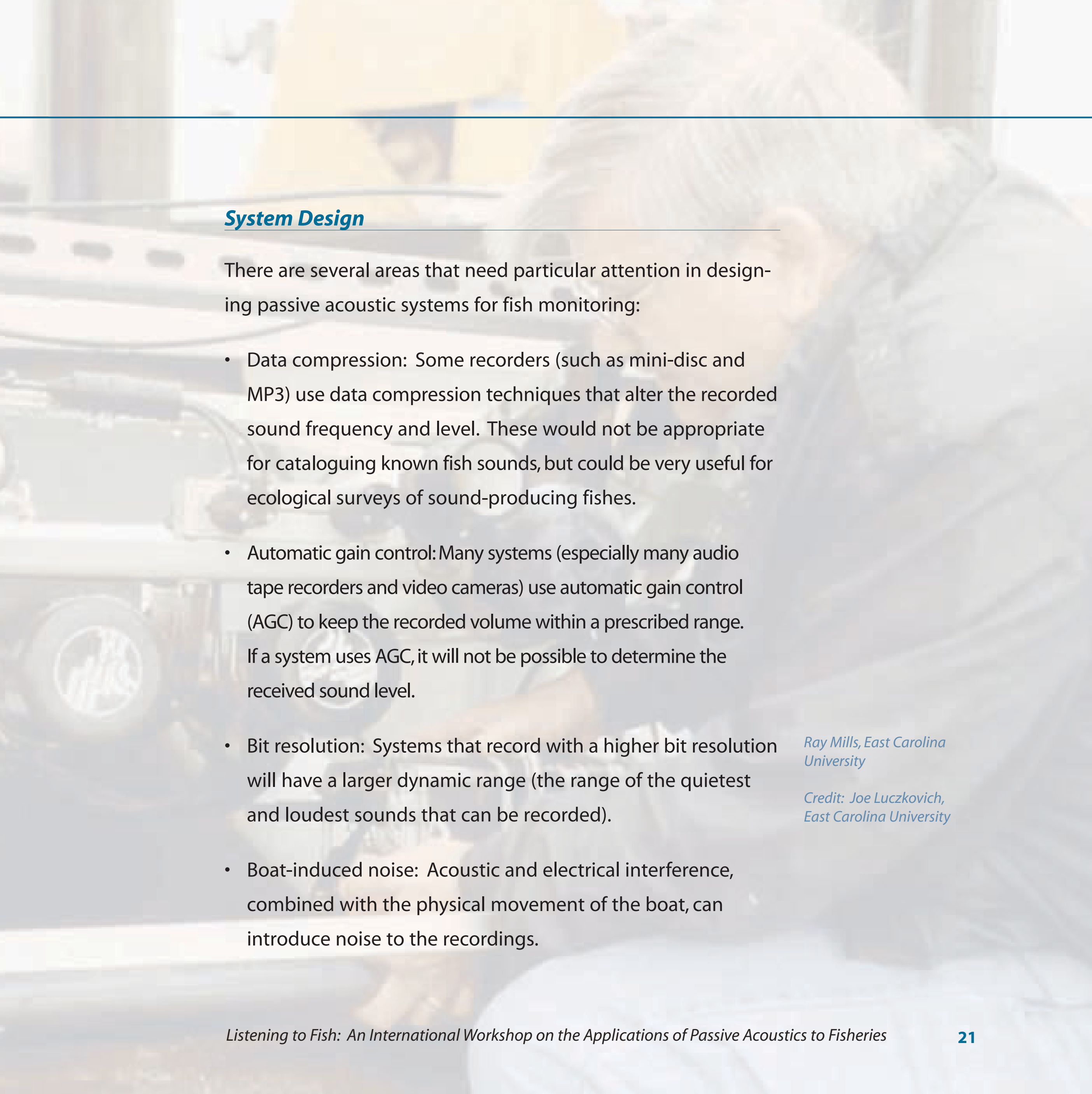
Credit: Tony Hawkins, FRS Marine Laboratory, Aberdeen, Scotland

Hydrophones

Hydrophones are the most basic element of any recording system. They are underwater microphones that typically convert sound pressure into an electrical signal that can be recorded by a data acquisition system. There are many commercial suppliers of hydrophones that are appropriate for fish sound recordings.

Data acquisition systems include audio and digital tape recorders, audio-video recorders, and computers with sound cards. Digital systems provide obvious advantages over analog systems in terms of greater frequency bandwidth and dynamic range and will be the most commonly used systems in the future.

Computer systems that are practical for recordings made in the laboratory may not be practical in a field situation because of power and portability issues. Tethered and autonomous underwater listening stations for monitoring sound-producing fishes are essential tools for determining which species produce which sounds, especially for species that are difficult to maintain in a laboratory tank. Systems that include video imaging are also useful for documenting behavior of fish aggregations.



System Design

There are several areas that need particular attention in designing passive acoustic systems for fish monitoring:

- Data compression: Some recorders (such as mini-disc and MP3) use data compression techniques that alter the recorded sound frequency and level. These would not be appropriate for cataloguing known fish sounds, but could be very useful for ecological surveys of sound-producing fishes.
- Automatic gain control: Many systems (especially many audio tape recorders and video cameras) use automatic gain control (AGC) to keep the recorded volume within a prescribed range. If a system uses AGC, it will not be possible to determine the received sound level.
- Bit resolution: Systems that record with a higher bit resolution will have a larger dynamic range (the range of the quietest and loudest sounds that can be recorded).
- Boat-induced noise: Acoustic and electrical interference, combined with the physical movement of the boat, can introduce noise to the recordings.

Ray Mills, East Carolina University

Credit: Joe Luczkovich, East Carolina University

- Dataloggers: Audio dataloggers are useful for recording over long periods of time in many locations simultaneously. Computers are the best option for such recording when continuous power is available. However, this is rarely the case in field situations, and low-power battery-operated dataloggers are required. Recent adaptations of consumer-type high-capacity digital recording devices offer the low-cost, reliable operation needed for fieldwork.

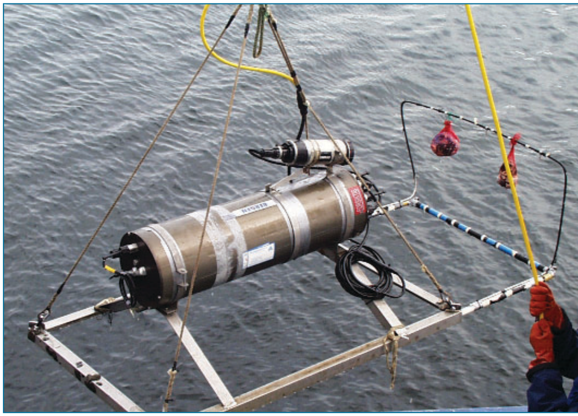
NOMAD technology

Credit: Cliff Goudey, MIT Sea Grant

- Telemetry: Several types of telemetry systems are available, including sonobuoys (VHF), cell phone systems, and short-range microwave systems. All of these systems require line-of-sight between the transmitter and receiver, and a relatively high level of engineering to set up and maintain. Telemetry is also capable of delivering video to document behavior during sound production.

- Satellite telemetry: Over the horizon systems generally do not support the bandwidth needed for transmitting acoustic data. However, some amount of preprocessing could allow data on sound to be transmitted.

- Hydrophone arrays: Multiple hydrophones can be used for localizing sound sources and producing a directional receiver (beam forming) to improve the signal-to-noise ratio.



Deployment of remote-controlled instrument platform

Credit: Jan Tore Ovredal, Institute of Marine Research, Bergen, Norway

- Underwater speakers: Sound sources are needed for conducting playback experiments to determine the reaction of fish to different types of sounds. Unfortunately, frequency response variations of most underwater projectors require processing of the signals to produce an accurate reproduction of a fish sound.

- Signal processing software: In addition to commercially available data acquisition and signal processing products such as MATLAB (Mathworks, Inc.), there are software packages designed specifically for bioacoustics research (e.g., Signal, Canary, and Avisoft).

- Automatic identification: Tools for automatically identifying species and analyzing long data sets are needed and will require the development of a library of fish sounds.

The Future of Passive Acoustics

Gloucester Harbor, Gloucester, MA

Credit: Madeleine Hall-Arber, MIT Sea Grant College Program

Although studies described during the workshop reflect the rapid growth of research on passive acoustic applications to fisheries and marine census, workshop participants identified a number of areas in which scientific and technical developments are needed to enhance our understanding of fish and promote future research:

Research Needs

- Quantifying the size of fish aggregations through a combination of passive and active acoustics.
- Linking the passive acoustical work to behavioral work (with more video and audio recordings made together where visibility allows).
- Modeling the propagation of fish sounds in different environments.
- Correlating sounds from specific habitats with overall environmental quality.
- Developing directional arrays and beam-forming technologies to precisely locate the sound sources in dark or turbid waters.

- Determining the size, sex and maturity of fish producing sounds.

- Determining what proportion of the fish are calling at a given time.

- Determining and modeling how sound pressure levels vary with shoal size and distance from sound source.

- Modeling of chorusing behavior. Are individual fishes calling together, i.e., are the choruses synchronized?

- Securing funding for establishment of long-term remote listening stations at established sites so that spatial and temporal (diurnal and seasonal) variations in sound are characterized.

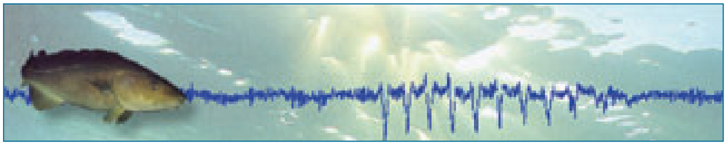
- Establishing a national center in the U.S. for the study of bioacoustics of fishes.

- Conducting these studies in ways that will allow testing of specific scientific hypotheses in collaboration with physical, chemical, and biological oceanographers.

- Conducting more research on the impact of fishing gear, boats, pipelines, dredging, petroleum exploration seismic surveys, and military operations on soniferous fishes.

Software Needs

- Improvements are needed in sound recognition systems. Such systems would make it possible to automatically distinguish calls of different species. Advances in the use of wavelet analysis and other new techniques have already shown that it is possible to distinguish the voices of individual male haddock.



Cod and waveform

Credit: Jan Tore Øvredal, Institute of Marine Research, Bergen, Norway

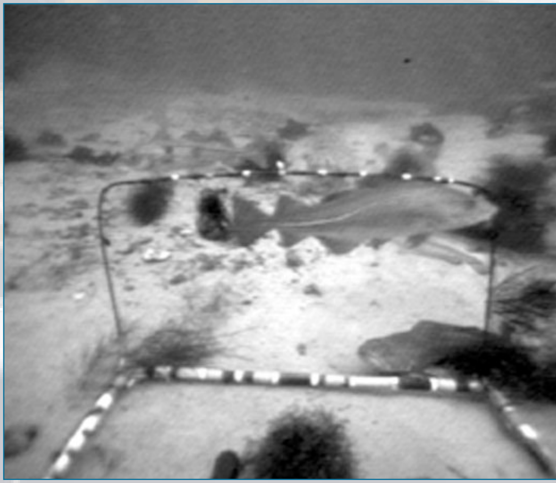
- Automatic event detection/analysis software is needed to quantify temporal patterns of sounds over long time periods.

- Robust software is needed for localization and tracking of sources.

- Software is needed to allow simultaneous analysis of video and audio data in behavior studies. This capability would allow the rapid correlation of individual sounds and sound components with behavior and functional morphology.

Hardware Needs

- Improved ship-based listening systems are needed, including dangling and towed hydrophones.
- Bottom-mounted listening systems are needed for determining the temporal patterns of fish sounds. Robust, low-cost systems are especially important.
- Drifting sonobuoy systems are needed, either storing the data, or telemetering data to ships or shore-based listening stations.
- Large hydrophone arrays are needed to localize sound sources.
- Systems are needed to measure source levels and calibrate listening devices so that researchers can determine the distance to sound sources.



Cod and cusk being recorded with the remote-controlled instrument platform

Credit:
Jan Tore Øvredal, Institute of Marine Research, Bergen, Norway

- Unmanned, archival acoustic recorders are needed for use on ships of opportunity.
- Systems are needed that allow simultaneous recording of both audio and video data, including the use of small, quiet ROVs that can be used from small boats.
- More robust field equipment is needed for shore-based or small-boat surveys in shallow water and estuaries.

Most fish bioacousticians are biologists first and engineers second. They have arrived at fish bioacoustics because it is a powerful tool for studying fish—one unmatched by other approaches. This means that engineering and signal-processing principles must be learned on the job.

Unfortunately, there is no one good source of information about recording and signal processing that is accessible and practical for the fish bioacoustician.

Mark Sprague
East Carolina University

Credit: Joe Luczkovich, East Carolina University

This gap can be bridged both by producing these targeted materials and conducting training workshops, and by attracting engineers with a biological interest to the field. The workshop participants identified a strong need to educate scientists, managers and the public on the uses of passive acoustic. It was also recognized that passive acoustics technologies provide a unique public outreach potential. Scientists and laymen alike are often fascinated by the phenomenon of underwater sounds. Passive acoustic technologies are amenable to multimedia display via the Internet and have great potential as public education and outreach tools.

Sebastian Inlet, Florida

Credit: Mrs. Marge Beaver

The Opportunity

Research presented at MIT Sea Grant's April 2002 workshop underscores the great strides that have been made in the application of passive acoustics to fisheries and related issues in the last two decades. It is clear from this body of work that while passive acoustics is currently underutilized as a research tool, it is rapidly emerging and holds great promise for the future. Thus, it is critical that funding agencies be made aware of the potential of passive acoustics in research on fish and fisheries. Passive acoustic approaches can provide fish biologists and fishery scientists with a non-destructive sampling tool offering a unique perspective on the biology and ecology of

soniferous species of fishes. The advances in underwater technology of the last two decades provide us with an opportunity to embark on a major new initiative in marine science. Listening to fish and other underwater sounds should be actively promoted and incorporated as a standard research tool in marine science.

Credits:

Edited by Rodney Rountree[1], Cliff Goudey[2], Tony Hawkins[3], Joeseph J. Luczkovich[4] and David Mann[5]

[1]School for Marine Science and Technology, UMASS Dartmouth, 706 South Rodney French Blvd., New Bedford, MA 02744

[2]Center for Fisheries Engineering Research, MIT Sea Grant College Program, Bldg. NE20-376, 3 Cambridge Center, Cambridge, MA 02139

[3]Environment & Society at the University of Aberdeen, St Mary's, Kings College, Aberdeen, AB24 3UF, UK

[4]Institute for Coastal and Marine Resources (Old Cafeteria Complex) Department of Biology (Howell Science Complex N-418), East Carolina University, Greenville, NC 27858

[5]USF College of Marine Science, 140 Seventh Avenue South, St. Petersburg, FL 33701-5016

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Massachusetts Institute of Technology
Sea Grant College Program
77 Massachusetts Avenue
Room E38-300
Cambridge, MA 02139

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