Future Tech Development in Underwater Observation

Passive Acoustics

By Dr. Rodney Rountree

Observational Technologies

As an ecologist interested in observing the behavior of marine animals in their natural environment, there appears to be a disconnect between the technology industry and the needs of ecologists.

Basically, ecologists often have to settle for technologies developed for scientists/users from other disciplines, getting what could be called "hand-me-down" technology … "hand-me-down" not in the sense of its being old or used, but rather just not quite what the ecologist wants.

First they are often limited to a single observation modality. There are many types of observations I may want to make underwater in support of behavioral studies (e.g., spawning), ecological studies (e.g., census of populations or species assemblages), habitat mapping (e.g., percent coverage of a habitat type), etc.

In nature there are many ways, or modalities, in which humans or other animals can observe their environment. Humans are highly biased towards visual observations that correspond to optic technologies. Another important way to make observations is through hearing, which translates to acoustic technology. Other ways to observe nature have rarely been translated into observational technologies: chemoreception (smell and taste), mechanoreception (complex of related senses, including equilibrium and balance, touch or tactile, "distance-touch", and hearing), electroreception (detection of electric fields), and magnetoreception (detection of magnetic fields).

The development of observational technologies designed to emulate human sensory systems and observational strategies will become increasingly important in the coming decades and will greatly enhance our understanding of underwater ecosystems.

Passive Acoustics

Considering acoustics more closely, note that there are at least three different types of acoustic observations that can be made, each of which conveys different information to animal observers:

1) simple hearing or listening,

2) echolocation via projecting a sound and listening for its reflection, and

3) distance-touch, or detection of mechanical disturbances in water through the lateral line.

The listening acoustic modality corresponds to passive acoustic technology, while echolocation corresponds to active acoustic technology (e.g. sonar, bioacoustics). Interestingly although echolocation is relatively rare in the animal kingdom, it is the most frequently applied acoustic technology in the marine sciences. In contrast, passive acoustic technologies have only recently been recognized as both underutilized and of great potential in marine ecology fields of study, particularly in fisheries science. In its simplest form, passive acoustics is the act of listening to the underwater sounds made by fishes and other animals in order to observe their behavior and environmental requirements.

This new technology is appealing because it provides scientists with an additional tool to put into their toolbox along with more traditional optic and active acoustic technologies, and because it provides the potential for remote observation over extended time periods (i.e., 24/7 realtime remote observations) at a relatively low cost.

Fisheries scientists and ecologists can use passive acoustic technology in many ways. One of the most important uses is as a non-invasive method of finding fish and other noise making animals. It is important to realize that sounds can be produced both actively and passively, that is deliberately as a form of communication (e.g., courtship and disturbance calls), and incidentally as a by product of a particular behavior (e.g., swimming and feeding). In either case, those sounds can be used to detect the presence of the animal. In cases where the behavior associated with sound production is known, passive acoustics can be use to map the spatial and temporal distribution patterns of that behavior.

For example, if we know the spawning sound of a particular fish, then we can use passive acoustics to map the distribution of spawning sites. In fisheries applications, that makes passive acoustics a very powerful tool for identification of essential fish habitat (EFH) which is mandated for all managed species by the United States Congress as part of the 1996 reauthorization of the Magnuson-Stevens Fishery Conservation and Management Act. However, the potential of passive acoustics as a tool for exploration and discovery is equally important.

In the open ocean, finding fish is often the biggest challenge to their study. After all, you can't observe and study something that you can't find!

Therefore, tools that allow investigators to determine the location of both known and unknown sounds can be a powerful tool in many habitats like the deep sea. It seems that passive acoustics has opened up a whole new frontier in marine science, and the frontier is right at our doorstep. It is hard to image how we have so badly overlooked the importance of the underwater soundscape to marine life, especially to fishes and invertebrates. But this is rapidly changing as more and more scientists realize the potential of the field. In the last decade pioneering studies have used passive acoustics to map spawning habitats of important estuarine fishes, record and study spawning behavior of fishes in a variety of settings, study the impact of man-made noise on marine animals, and to locate and track marine mammals and fishes.

With my colleagues Cliff Goudey at the Center for Fisheries Research Engineering and Francis Juanes at the University of Massachusetts Amherst, we have recently made the first field recordings of cod and haddock in North American waters and have begun to study the natural daily pattern of spawning in haddock. We have doc-

Figure 1. Examples of typical field conditions for passive acoustic applications in ecology.

umented abundant unknown biological sounds in deep sea canyons south of Georges Bank, on the commercial fishing grounds in the Gulf of Maine, in the Stellwagen Bank National Marine Sanctuary, in the estuaries of Cape Cod Massachusetts, including the docks of Woods Hole Massachusetts, and even on the docks of New York City in Manhattan. The latter two examples are notable in that the waters around Woods Hole, Massachusetts are among the most intensively studied areas in the world, yet passive acoustics has opened up a whole new area of discovery. Similarly, many people would be surprised to find that new frontiers in marine science can be found right off the docks of New York City, right in the heart of the industrial world. Most recently we have documented widespread biological sounds in the ponds, lakes and river systems of New England. Most of these sounds have never been described and their sources are currently unknown. To me, that makes passive acoustics all the more exciting as new discoveries are made just about very time we lower a hydrophone into the water.

Acoustic Software Development

Although there is no doubt that passive acoustics will become increasingly important in the coming years, there are significant technological obstacles that have slowed the growth in the field. One of the most important obstacles currently limiting the application of passive acoustics in marine ecology and fisheries is a lack of specialized soft-

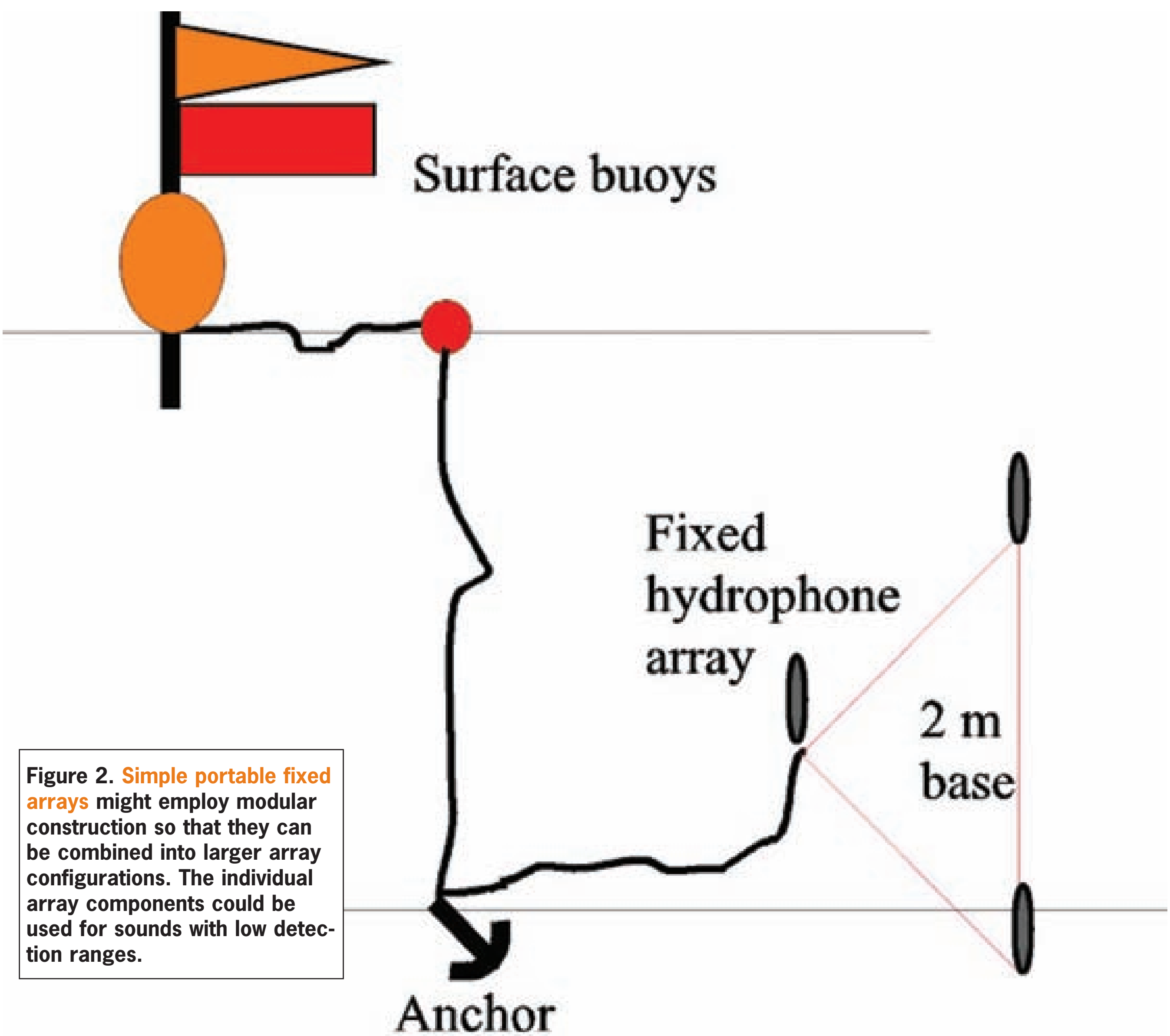

Figure 2. Simple portable fixed arrays might employ modular construction so that they can be combined into larger array configurations. The individual array components could be used for sounds with low detection ranges.

ware for field recording and data processing. Like other observational technologies, passive acoustics often produce a daunting amount of digital data that must be processed either in real time or during post processing. To be sure, investigators around the world have had various amounts of success developing automatic detection algorithms for marine mammals and fishes, but efforts have not yet been translated to technologies readily available to others. In addition, we need much more robust programs capable of recognizing and classifying both known and unknown biological sounds. It is important to note that often the temporal and spatial context of a detected sound is just as important as the sound itself.

Therefore, auto-detection programs should provide information on the relative and absolute time reference for each sound. In addition programs that can automatically provide statistical data on sounds, such as duration, dominant frequency, pulse rate, pulse width, pulse number, etc., are much desired. The ability to compile large sample sizes for these parameters is vital to ecological studies. Software development is a challenging area of passive acoustic research, but promises great intellectual and commercial rewards. The development of advanced passive acoustic instrumentation beyond existing systems currently used by a few laboratories for specialized studies, into robust systems that can be made available off-the-shelf for a variety of uses is dependent on the development of more robust acoustic software.

A particularly desirable array system would provide an integrated display of the array configuration (array element locations), with a GIS display of bathymetry, water temperature and other available environmental variables, together with real-time locations of both known and unknown sounds. Such a system would top my Christmas wish list!

Shore-based Passive Acoustic Systems

The "bread-n-butter" technology needed for further expansion of the field will be low-cost, hand-held systems that will become a standard component of academic, industry and government research and monitoring programs right alongside seine nets and environmental probes. However, currently investigators have to cobble together sound digitizing and recording equipment never intended for field use, let alone use around water. Unfortunately, these make-shift systems lack many specific components or options that investigators quickly discover needing upon attempting to conduct a passive acoustic survey. Among the most important needs are integrated systems (hydrophones, digitizer, recording system and software) that run off of a single power source, can be used in various lighting conditions, have real-time monitoring and playback capabilities, and have accurate and calibrated gain control options. Just as importantly we need specialized software designed for field use in rugged marine and aquatic habitats. Currently there are many

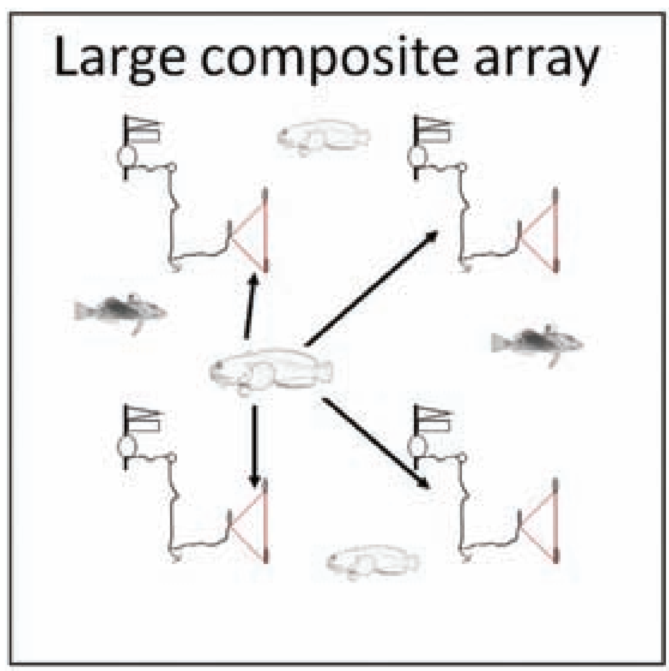

Figure 3. A large composite fixed array composed of multiple modular arrays to allow localization of sounds on different spatial scales.

"canned" acoustic software packages available on the market, but each have one or more significant drawbacks for the field ecologist:

1) lack of automatic calibration to determine received source levels,

2) require full windows or Mac operating systems (i.e., cannot easily be integrated into specialized hardware),

3) multichannel recording systems often lack options for separate channel calibration and playback,

4) program screens are optimized for desktop use and are difficult to navigate in harsh field conditions with highly variable light conditions,

5) often lack options to incorporate good signal autodetection algorithms (i.e., ones that actually work for fish sounds, especially in noisy environments), and

6) often lack robust sound source localization options. In short, most systems are designed for laboratory or terrestrial field conditions and for biologists working with bird sounds, and not for underwater sounds and marine field conditions.

To illustrate an example of a fish ecologist application, I recently conducted a shore-based survey of rivers in New England where I sampled from docks, sea walls, river banks, bridges, mountain streams, large lakes, small ponds, large estuaries, etc. I often had to scramble over large rocks, down steep banks, through streams, through heavy woods, etc., all carrying a laptop and other cumbersome equipment. Often I had to toss the hydrophone some distance across a bank or off a bridge to reach the water. Did I mention I was sometimes working in either complete darkness, or in sun so bright I could not see the laptop screen? This type of work demands equipment that is highly mobile, flexible, and protected from the elements.

Portable Arrays and Localization of Sound Sources

Another exciting and challenging area of passive acoustic technology development is of portable hydrophone array systems. Hydrophone arrays are needed to localize sound sources so that ecologists can collect data on animal association with habitat and environmental conditions on course and fine scales. In some cases arrays can be used to count, and hence, census marine animals, though the high mobility, intermittent calling, and other aspects of fish behavior make this difficult or impossible for many fishes. One often overlooked, but important byproduct of sound source localization is the determination

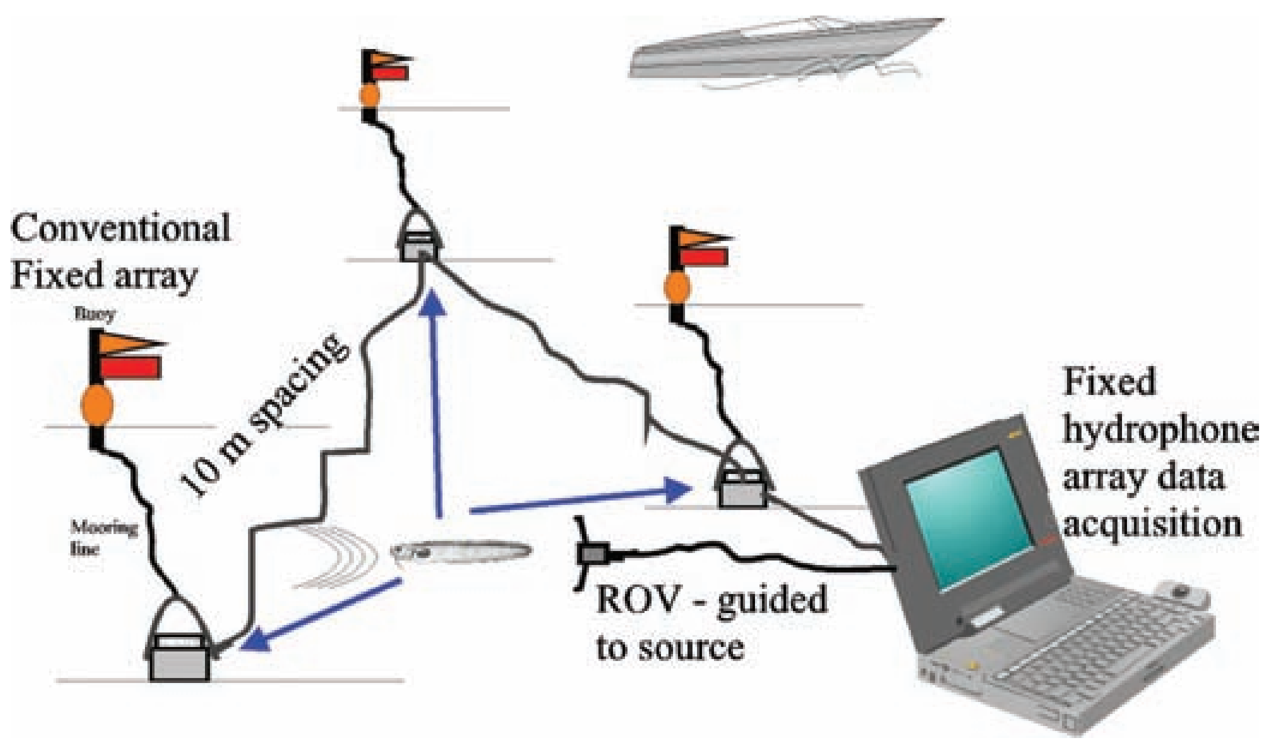

Figure 4. Illustration of use of a fixed array to guide an ROV to a target sound source.

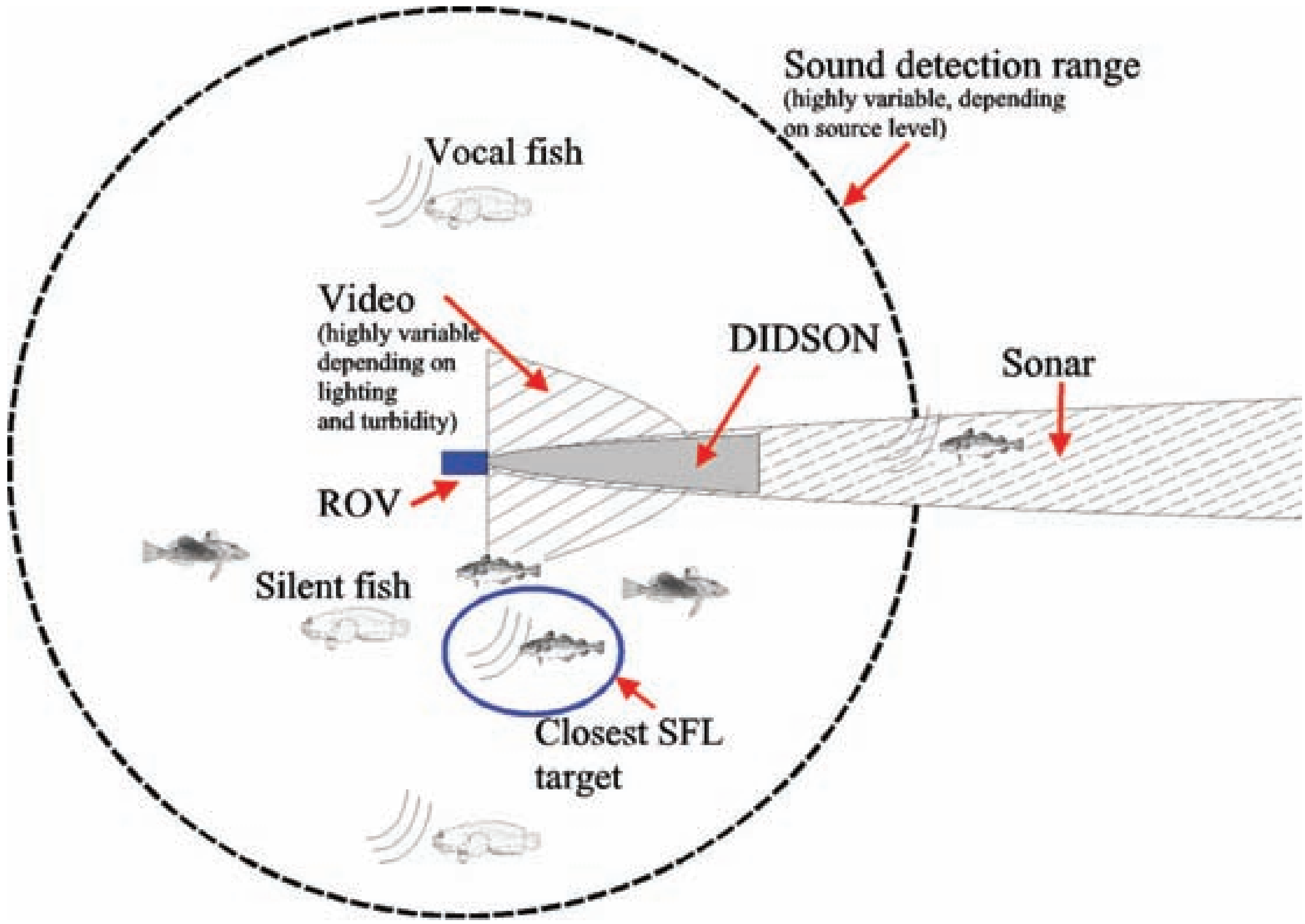

Figure 5. Soniferous fish location device (SFL) with integrated optic and acoustic sensors to aid in the identification of unknown sound sources.

of sound source level (rather than just received sound source levels). Good data on sound source levels, and hence, detection ranges, are a prerequisite for broad-scale spatial mapping of animal distributions and habitat associations. Another important use of localization is to provide clues that can aid in the identification of unknown sounds.

Currently most biological sounds recorded in marine and aquatic habitats are unknown due to the lack of study and a general lack of comprehensive sound catalogues. Localization provides clues such as whether the source is stationary or mobile, from single or multiple locations, near the bottom, in the water column, near the surface, nearby or far away, etc. Often this type of information can narrow down the field of possible sound source candidates at a given location. However, positive identification of sound sources requires either laboratory or field validation (i.e., actual observation of an animal calling). Because laboratory observations are often impractical or impossible, arrays that are integrated with other technologies that can provide field proof of the sound source identity will be vital to future passive acoustic research.

The development of portable array systems is not as easy as it sounds due to the spatial scale required to localize on fish and marine invertebrate sounds, and to the requirements of marine ecologists. Typically fish vocalize at between 50 and 2000 Hz, and often between 100-500 Hz. Thus hydrophone spacing needs to be on the order of meters to 10's of meters, so small arrays typical of other acoustic tracking applications are not generally possible. Unfortunately, precise positioning of hydrophones in arrays at this spatial scale is often not possible due to depth or other logistical limitations, so methods of system self determination of array element locations are needed, even if only of relative distances among elements. Systems that can be quickly deployed, retrieved, and re-deployed in a variety of habitats and environmental conditions are desired. A particularly desirable array system would provide an integrated display of the array configuration (array element locations), with a GIS display of bathymetry, water temperature and other available environmental variables, together with real-time locations of both known and unknown sounds. Such a system would top my Christmas wish list!

Sound Source Identification

As previously mentioned, one of the most important, and exciting uses of hydrophone array systems is for identification of unknown sound sources. In some limited cases, such as on coral reefs where visibility is good, source identification can be achieved by mounting underwater video cameras on the array. Even here, though, better integration of acoustic and video data is needed. Further, video systems require the use of artificial lights that can greatly limit deployment options due to high power requirements. More importantly, artificial lights will often have a strong influence on animal behavior and many animals may not exhibit vocal behavior in their vicinity. In these cases, systems that integrate other observation technologies such as acoustic imaging have the greatest promise. But so far we have been talking about fixed arrays and even acoustic imaging has only a limited range. How do we determine the identity of unknown sounds over larger spatial scales? One option is to use location data derived from an array to guide an ROV, AUV, UUV, Glider or other mobile gear to the sound source location where they can utilize integrated optic, sonar, and acoustic imaging sensors to identify the source. The ultimate technology would be the development of an autonomous "Soniferous fish Locator" (SFL) device as originally envisioned by the late Joe Blue and myself. The SFL could be mounted on various mobile platforms, and could be used to locate sound sources in one of two ways depending on the sound source characteristics. In some cases, the SFL could locate the sound and directly guide the mobile platform to the source location. In other cases, the SFL could allow the platform to home-in on the sound source through the process of null steering. In either case, the SFL technology could open up an exciting new field of underwater exploration.

Conclusion

Passive acoustic technology promises to become an important component of many fields of marine science in the coming decades. It will be particularly important to the exploration of the seas in that it can provide a powerful new tool for locating animals and observing their behavior remotely and over long time periods. For the marine technology industry, passive acoustics promise both exciting challenges in hardware and software development and in the integration of different technologies, but also great commercial opportunities due to its usefulness in a wide range of applications and disciplines.

About the Author

Dr. Rountree has over 20 years experience as a marine ecologist, and has managed multidiciplinary estuarine and fisheries programs for the National Marine Fisheries Service and the University of Massachusetts. In recently years he has become recognized as an international leader in the development of passive acoustic technology applications to fisheries. He recently founded a small consulting firm, Marine Ecology and Technology Applications, Inc., in East Falmouth, Massachusetts which conducts basic research, provides public education and outreach, and provides consultation to the technology industry on applications of advanced technologies in the fields of marine ecology and fisheries. He maintains an extensive research web site at http://www.fishecology.org. His business web site is

http://www.marineecologyandtechnology.com