

## *Workshop Proceedings*



## **Underwater Passive Acoustic Monitoring for Remote Regions**

*Hawaii Institute of Marine Biology, Coconut Island, Hawaii  
February 7-9, 2007*

*Funded by NOAA's Coastal Services Center through  
the Alliance for Coastal Technologies (ACT)*



**An ACT 2007 Workshop Report**

**A Workshop of**

**Research Scientists, Technology Developers, and Resource Managers**

# **Underwater Passive Acoustic Monitoring for Remote Regions**

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## EXECUTIVE SUMMARY

The Alliance for Coastal Technologies (ACT) convened a workshop, sponsored by the Hawaii-Pacific and Alaska Regional Partners, entitled *Underwater Passive Acoustic Monitoring for Remote Regions* at the Hawaii Institute of Marine Biology from February 7-9, 2007. The workshop was designed to summarize existing passive acoustic technologies and their uses, as well as to make strategic recommendations for future development and collaborative programs that use passive acoustic tools for scientific investigation and resource management. The workshop was attended by 29 people representing three sectors: research scientists, resource managers, and technology developers.

The majority of passive acoustic tools are being developed by individual scientists for specific applications and few tools are available commercially. Most scientists are developing hydrophone-based systems to listen for species-specific information on fish or cetaceans; a few scientists are listening for biological indicators of ecosystem health. Resource managers are interested in passive acoustics primarily for vessel detection in remote protected areas and secondarily to obtain biological and ecological information. The military has been monitoring with hydrophones for decades; however, data and signal processing software has not been readily available to the scientific community, and future collaboration is greatly needed.

The challenges that impede future development of passive acoustics are surmountable with greater collaboration. Hardware exists and is accessible; the limits are in the software and in the interpretation of sounds and their correlation with ecological events. Collaboration with the military and the private companies it contracts will assist scientists and managers with obtaining and developing software and data analysis tools. Collaborative proposals among scientists to receive larger pools of money for exploratory acoustic science will further develop the ability to correlate noise with ecological activities. The existing technologies and data analysis are adequate to meet resource managers' needs for vessel detection. However, collaboration is needed among resource managers to prepare large-scale programs that include centralized processing in an effort to address the lack of local capacity within management agencies to analyze and interpret the data.

Workshop participants suggested that ACT might facilitate such collaborations through its website and by providing recommendations to key agencies and programs, such as DOD, NOAA, and IOOS. There is a need to standardize data formats and archive acoustic environmental data at the national and international levels. Specifically, there is a need for local training and primers for public education, as well as by pilot demonstration projects, perhaps in conjunction with National Marine Sanctuaries. Passive acoustic technologies should be implemented immediately to address vessel monitoring needs. Ecological and health monitoring applications should be developed as vessel monitoring programs provide additional data and opportunities for more exploratory research. Passive acoustic monitoring should also be correlated with water quality monitoring to ease integration into long-term monitoring programs, such as the ocean observing systems.

## ALLIANCE FOR COASTAL TECHNOLOGIES

The Alliance for Coastal Technologies is a NOAA-funded partnership of research institutions, resource managers, and private sector companies dedicated to fostering the development and adoption of effective and reliable sensors and platforms. ACT is committed to providing the information required to select the most appropriate tools for studying and monitoring coastal environments. Program priorities include transitioning emerging technologies to operational use rapidly and effectively; maintaining a dialogue among technology users, developers, and providers; identifying technology needs and novel technologies; documenting technology performance and potential; and providing the Integrated Ocean Observing System (IOOS) with information required for the deployment of reliable and cost-effective networks.

To accomplish these goals, ACT provides these services to the community:

- Third-party testbed for quantitatively evaluating the performance of new and existing coastal technologies in the laboratory and under diverse environmental conditions.
- Capacity building through technology-specific workshops that review the current state of instrumentation, build consensus on future directions, and enhance communications between users and developers.
- Information clearinghouse through a searchable online database of environmental technologies and community discussion boards.

The ACT workshops are designed to aid resource managers, coastal scientists, and private sector companies by identifying and discussing the current status, standardization, potential advancements, and obstacles in the development and use of new sensors and sensor platforms for monitoring, studying, and predicting the state of coastal waters. The workshop's goal is to help build consensus on the steps needed to develop and adopt useful tools, while facilitating critical communication among the various groups of technology developers, manufacturers, and users.

ACT Workshop Reports are summaries of the discussions that take place between participants during the workshops. The reports also emphasize advantages and limitations of current technologies while making recommendations for both ACT and the broader community on the steps needed for technology advancement in the particular topic area. Workshop organizers draft the individual reports with input from workshop participants.

ACT is organized to ensure geographic and sector involvement:

- Headquarters is located at the UMCES Chesapeake Biological Laboratory, Solomons, MD.
- Board of Directors includes Partner Institutions, a Stakeholders Council, and NOAA/CSC representatives to establish ACT foci and program vision.
- There are currently eight ACT Partner Institutions around the country with coastal technology expertise that represent a broad range of environmental conditions for testing.
- The ACT Stakeholder Council is comprised of resource managers and industry representatives who ensure that ACT focuses on service-oriented activities.



ACT is committed to exploring the application of new technologies for monitoring coastal ecosystem and studying environmental stressors that are increasingly prevalent worldwide. For more information, please visit [www.act-us.info](http://www.act-us.info).

## ORGANIZATION OF THE WORKSHOP

This workshop was sponsored by the ACT Hawaii-Pacific and Alaska Regional Partners and hosted by the Hawaii Institute of Marine Biology, School of Ocean and Earth Science and Technology, University of Hawaii. The workshop was organized by Melissa Bos and Dr. Marlin Atkinson of the Hawaii Institute of Marine Biology and Dr. Shannon Atkinson of the Alaska Sea Life Center. Participants arrived on Wednesday, February 7, 2007 at the Hawaii Institute of Marine Biology at Coconut Island and gathered for a reception and dinner, during which a presentation on ACT was given by Dr. Marlin Atkinson. A keynote address describing a personal history of applying passive acoustic tools to resource management was given by Dr. Rusty Brainard of NOAA Fisheries Coral Reef Ecosystem Division.

The workshop discussions commenced the next day, beginning with the workshop vision and goals. Participants were split into sectors (research scientists, resource managers, and technology developers) for breakout session #1. Each group reported back to the plenary before lunch. In the afternoon, participants were divided into two mixed groups for breakout session #2. They discussed questions that surfaced in the morning discussions and presented back to the plenary at the end of the day. On Friday, February 9, the participants brainstormed recommendations and action items. The workshop concluded with a vote on priority recommendations.

## MOTIVATION FOR WORKSHOP

A needs assessment was conducted in Hawaii during the summer of 2006. Scientists and resource managers from all of the main Hawaiian Islands and several Pacific Islands were interviewed individually and in small groups. When asked about future workshop topics, 89% of interviewees supported the topic of passive acoustics, a significantly higher level of support than for any other topic. The momentum behind passive acoustic monitoring programs has been building as scientists and managers discover the benefits of this type of sensor. ACT responded by developing the *Underwater Passive Acoustic Monitoring for Remote Regions* workshop.

This workshop also represents a unique collaboration between two ACT regions. The Hawaii-Pacific Regional Partner teamed up with the Alaska Regional Partner to host the workshop when common needs and goals were identified. In the Hawaii-Pacific region, hydrophone-based systems are primarily needed for monitoring coral reef ecosystem health and vessel traffic in marine managed areas. In the Alaska Region, hydrophone-based systems are primarily used for cetacean management, although they are also employed for fisheries management as well.

Hydrophone-based systems are relatively inexpensive and easy to operate and maintain. They are versatile and have the potential to monitor a wide range of biological and anthropogenic behaviors and events. In addition, they can be remotely deployed and the data can be analyzed with

processing software, both of which considerably reduces personnel costs in monitoring programs. Hydrophone-based systems function equally well during the day and night, and their function is less compromised by biofouling than optical sensors.

The workshop aimed to identify the status of underwater passive acoustic systems, the gaps and challenges facing implementation, and the action items needed to advance the field. Participants were chosen with intentional diversity of biogeographic region, background / training, and application of hydrophone-based systems.

### **BREAKOUT SESSION # 1: STATUS OF EACH SECTOR**

Participants were organized into three breakout groups based on their primary role: resource managers, technology developers, and research scientists. Many participants felt equally allied with two or more groups and had to choose the best fit; this was especially true of academic scientists who are developing their own technologies.

Each group was given two hours to summarize the status of passive acoustic technology in their respective sector. A list of discussion questions was provided to each group (included below). Each group elected a spokesperson who was given 15 minutes to report back to the plenary, followed by a five minute question and answer period. The results of these discussions are presented below.

#### **Resource Managers**

The Resource Management Group was asked to discuss and summarize the following:

- What resources do you manage? Describe the biological, political, socio-economic, and geographical attributes of your management area. Also describe your staff in terms of quantity and training.
- Describe your current monitoring program(s).
- What management challenges do you face that passive acoustic monitoring may address?
- Is there more interest in using passive acoustics for biological monitoring or for surveillance / enforcement?
- How has passive acoustic monitoring been used to aid coastal resource management in your areas? What challenges appeared?
- What is limiting you from using passive acoustics (e.g., money, training, appropriate tools, etc.)?
- Describe an ideal passive acoustic tool for your needs, including data storage and analysis mechanisms.

The eight-member group represented a variety of habitats and management environments (see summary table on next page). Some commonalities that surfaced were:

- Many managers are responsible for large, remote regions that are far from population centers and difficult to access due to logistics, limited financial and human resources, and environmental hazards
- Management staff is often inadequately trained to operate sensors and analyze / interpret data, so a centralized system is of interest

- Most managers are eligible to apply for adequate pools of money to support passive acoustic work, but project-specific funding would be necessary in most cases, and support for passive acoustics would mean decreasing the amount of money spent on other management priorities

<b>Management Area Name</b>	<b># of Staff</b>	<b>Staff Training Level</b>	<b>Political Support</b>	<b>Description of Area</b>	<b>Resources</b>	<b>Funding</b>
Helen Reef, Palau	8	high school, local community members	supported	360 miles from capital of Koror, 270 sq mi	diverse and endangered land & water species	foundation grant support
Remote U.S. Pacific Islands	40	half have masters or above	strong nationally	55 islands, 1/4 global ocean, 1.5 million sq mi	monk seals, cetaceans, coral reefs, bottomfish	federal funds NOAA competitive grants
Main Hawaiian Islands	40	half have bachelors degree, half have higher degree	strong nationally	populous islands with coastal reefs	coral reef, pelagics, bottomfish, cetaceans and seals	federal grants and some state support
CNMI	30-40	10% have graduate degree, rest have bachelors or high school	variable	3 inhabited islands, 11 remote islands, 8 subsurface banks	sea turtles, coral reefs	mostly grants from US
NWHI	20	2 trained biologists	strong nationally	240 to 1200 mi from Honolulu, uninhabited and inaccessible	includes marine and terrestrial species	3 mill a year, federal non-competitive grants and earmark
Everglades National Park	8	high school with some college-level training	strong	shallow water, freshwater to marine transition, accessible	many endangered species	federal support
Alaska	large	high level	support but also dissension	remote, ice-covered, logistically-hard environment	huge fisheries and endangered marine mammals	high level federal and state

The Resource Management Group identified many challenges that passive acoustic tools may be better at addressing than other available approaches. Acoustics can detect many species of concern that standard visual methods miss because a) many coral reef species are cryptic, b) deepwater species are often missed in visual assessments, c) marine mammals spend 99% of their time below the surface, and d) visual methods do not accurately monitor nocturnal behaviors and events that are often of more concern than daytime occurrences. Remotely deployed instruments with long lifespans are in demand because management areas are often remote and difficult to access, fuel for enforcement and monitoring vessels can be prohibitively expensive, and severe weather might

exclude human access. Managers hope that passive acoustics will be a tool that can assist in focusing limited biological and human monitoring dollars.

Managers that had already used hydrophone-based systems mentioned several challenges they've faced to date. First, as with all deployed instruments, are the issues of theft and vandalism. There are reports that deployed hydrophones have been stolen from the water. A second challenge is the need for better spatial coverage in order to interpret the data. Following that, data analysis needs improvement. Managers need better ecological contexts for the noises that are recorded and the interpretation of sounds needs further scientific exploration. Additionally, funding is limited for personnel costs. Whereas funding for field work is relatively easy to obtain, funding for analysis is more difficult to secure. Lastly, when used for vessel traffic enforcement, a more accurate trigger is needed to turn the hydrophone on; however, as power and data storage capabilities increase, this last concern will be less of an issue.

The Resource Management Group found general consensus on what they desire from the technology developers. For near-term applications, they described a tool to help focus enforcement within marine areas, highlighting the following as important characteristics:

- deployable in remote areas
- resistant to weather extremes
- usable over the range of 0-500 meters
- inexpensive enough to allow for comprehensive spatial coverage
- able to store data for long periods (such as half a year to two years)
- data can be retrieved by passing over the surface in a boat without physically retrieving the instrument
- able to be tracked so instrument loss is minimized
- interfaces with or compatible with currently available software
- data analysis conducted by a partner organization with the ability to interpret the signals, and the data analysis cost is reasonable and considered from the beginning of a project

The tool described would allow managers to characterize many parameters of concern, such as poaching activity in their areas and would help them to focus the location and timing of enforcement activities.

The group also discussed idealized tools they would like to see in the future. First, they would like vessel monitoring hydrophones that can transmit data in real-time to enforcement officers to trigger enforcement actions. They would also like to see hydrophones that monitor biological behaviors and events, with signal processing that allows for accurate correlations of noises with ecologically important events. Most managers have more trust in the use of hydrophones for vessel monitoring and are more skeptical about their utility as biological monitors.

### **Technology Developers**

The Technology Development Group was asked to discuss and summarize the following:

1. Describe the passive acoustic technologies that are currently available. Include the following:
  - What parameters does it measure?

- Specifications like range, frequency, etc.
  - Required gear like computer, software, etc.
  - Cost
  - Examples of how it has been used
  - purchasing information
2. Describe what you see as the future of passive acoustic tools.
  3. What information do you need from the technology users (scientists and managers) to guide future development?
  4. Describe your ideal process for communicating with technology users and incorporating their needs into tool design and development.

The 10-member Technology Developers Group was a mix of commercial companies, academics, and one representative from the high-tech funding sector. They spoke of a wide variety of available instruments that can monitor fish, cetaceans, vessels, divers, biological functions, and coral reef health over the long-term and the short-term. The specifications of the instrument are a function of the question being asked, and companies need feedback from the user community to define these specifications.

Off-the-shelf hydrophones range in price from \$300 to \$3,000, and the cost is a function of sensitivity and bandwidth. The group expressed a desire for a “Consumer Reports” of hydrophones.

It was also noted that the Navy has a calibration facility in Florida, but good calibration may not be necessary and is often a waste of time.

Some challenges encountered with passive acoustic monitoring include: operations and maintenance of the instrument, the relatively young age of the community, and biofouling in estuarine environments.

It was agreed the future of the field is in real-time data telemetry. Triggers are being developed to turn instruments into the active mode and new algorithms are also being developed. However, new platforms still need to be developed.

The information needed by users to drive development includes:

- What maximum bandwidth is required?
- What maximum deployment time is required?
- Do you need real-time or post-signal processing?
- How many arrays do you need?
- What absolute decibel level do you need?
- Do you require a pre-filter?

The ideal process for communicating with users is to have a one-stop clearinghouse that has only commercial products available and is continually updated; an example of which is the Joe Blue hydrophone site that is no longer available. The group also suggested a community working group to discuss user issues and future development.

**Research Scientists**

The 12-member Research Scientist Group was asked to discuss and summarize the following:

- Describe your research program goals and projects. What percentage of your work is currently devoted to passive acoustics? What percentage of your work is currently devoted to any type of acoustics?
- What was your main motivation for studying passive acoustics?
- What is your focus: bio-acoustics or vessel monitoring (or other)?
- What is the spatial and temporal extent of your monitoring programs?
- Do you spend more time testing tools and equipment or using them in applications?
- How you would like to use passive acoustic monitoring in the future?
- What are the main challenges you face in using passive acoustic tools?
- Describe an ideal passive acoustic tool for your needs including data storage and analysis mechanisms.

The group prepared a table to summarize answers to some of the above questions ( below).

<b>NAME</b>	<b>Effort %</b>	<b>Use/Devel</b>	<b>Motivation</b>	<b>Spatial</b>	<b>Temporal</b>
RR	10	U	Discovery	Individ-Fish Grounds	Diel
JL	25	D	Fish Spawn Habitat	50km River Mouth	Diel-Month
DB	<5	U	Fish Spawn Habitat	Estuary	Diel-Seasonal
GW	30	D	Monitor/Enforce	20 km	Continuous
JH	100	D	Cetacean Stock Assessment	100 km	Decadal
OS	0		Regional monitoring change	100 km	Decadal
TG	10	U	Fish Spawn Habitat	10km	Hr-Year
AM	15	U	Ecological Understanding	1000 km	Diel-Seasonal
BL	5	U	Fisheries Stock Assessment	site specific	Diel-Month
PL	100	D	Fish Spawn Habitat	site specific 10m	Seasonal- Annual
SeaLife	<5	U	Integrated Observing	65 km	

The researchers varied from spending a small percentage of their time on passive acoustics (<5%) to being fully focused on the subject (100%). They were split evenly on the question of whether they spend more time developing tools or using them in research applications. The motivations for using passive acoustics were diverse and included monitoring fish spawning habitat, increasing ecological understanding, assessing cetacean and fisheries stocks, and integrated ocean observing applications. Researchers use passive acoustics to monitor on spatial scales ranging from individual fishing grounds to large areas (1000 km). Temporal scales are also varied; daily, monthly, seasonal, annual, and continuous timescales were all identified.

Researchers use passive acoustics to monitor cetaceans, fish stocks, environmental noise (natural and anthropogenic), invertebrates, forage species, climate change, and ecosystem health. They expressed a strong need for support, including financial support, for further investigative/exploratory research. Surveys are needed to catalogue known and unknown sounds, audition fauna for sound production, and identify unknown sounds and source behavior.

The Research Scientist Group also spoke of a need for better data organization and analysis. There is an abundance of data and interpretations, but uses of the data are lacking. Scientists would like

to partner with managers to address biological monitoring needs if the management issues support basic research efforts, but it must be a question-driven process. Further technology development is required for acoustic monitoring of biological activities.

**BREAKOUT SESSION #2: DIRECTED QUESTIONS FROM SESSION #1**

The discussions from breakout session #1 brought to light many key themes and issues that were addressed by four questions during the afternoon breakout session #2. The group assembled itself into two mixed breakout sessions with a fairly even spread of interests, focus areas, and geographic representation. Each group was asked to discuss the same four questions. A spokesperson for each group presented back to the plenary, and the cumulative feedback is summarized below.

**Question #1. Is it appropriate to identify and design inexpensive instruments for boat traffic and identified specific biological interactions (e.g., with endangered species)? If so, what are specifications for this instrument? How is it best to achieve this goal? Should there be an RFP for funding? Focus this discussion on management priorities.**

The group consensus was that it is appropriate to design inexpensive instruments for vessel detection and specific biological interactions and that such instruments would be very useful to the management community. It was suggested that, for vessel detection purposes, the instrument should sample at 4 kilohertz: 1 minute / 15 minute bursts. However, further work is required to specify data acquisition parameters in order to fulfill detection requirements.

For ecological monitoring, a statistical approach could be taken to correlating ambient noises with “healthy” versus “unhealthy” reefs. Scientists can select 10 healthy and 10 unhealthy reefs based on non-acoustical measurements and collect ambient noise data from both. This simple experiment can be used to establish simple correlations for bio-acoustical monitoring of reefs.

Managers are very interested in a spatially-comprehensive network of vessel detection sensors that could initially record vessel traffic for a half-year period and eventually transmit the data in real-time to trigger enforcement actions. There was some discussion regarding the costs of data storage versus real-time data transmission, and it was concluded that further investigation needs to be done to determine which is actually cheaper and more feasible. A summary of peak vessel days/times would allow managers to focus enforcement efforts; for example, if a high percentage of vessel signals in a protected area occurred on weekend nights, and none during weekdays, management may decrease the number of officers during weekdays and increase the number during weekend nights. Such a summary would also give managers an idea of which protected areas are being poached more often, thereby allowing them to focus enforcement efforts spatially. Real-time signal transmission would be ideal, as this would allow for real-time enforcement actions that increase the likelihood of a successful bust and decrease the costs of personnel and vessel fuel, as well as the risk posed to officer safety.

**Question #2. How should scientists and managers work together to move the field along? Managers need usable products now, and scientists need to conduct exploratory and hypoth-**

**esis-driven research to be able to interpret sounds and correlate them to events and behaviors. How do you strike a balance?**

Scientists and managers need to work more closely together and communicate more frequently about needs and potential solutions. The solutions likely exist to meet managers' needs, but the packaging and delivery of these solutions requires further collaboration.

Scientists and managers can work together on targeted proposals that seek larger sums of money for more focused applications. For example, managers can form partnerships with scientists to conduct vessel detection monitoring. Managers often do not have the capacity to analyze acoustic data, but a partnership with a group of scientists that does would be beneficial to both parties. Managers would obtain usable data, and scientists would have the use of funded hydrophone-based systems in remote regions to collect ecological and biological data. A balance may involve using the technology for a proven application now (such as vessel detection) while, at the same time, collecting ambient noise data for further exploratory scientific work. This was a recurring suggestion throughout the workshop.

**Question #3. Should there be central or standard processing of data? If so, who would do the processing, how would it be accomplished, and who would the clients be?**

All parties who collect acoustic data should adopt a standardized data format and include metadata in all files. National standards are currently being developed by the Acoustical Society of America (ASA); ACT does not need to facilitate a parallel effort.

Data should be archived at the national level. NOAA has several existing archival programs that could be partnered with, especially the National Geophysical Data Center (NGDC) and the Ocean Biological Information System (OBIS). The military has been archiving ocean noise data for over 60 years; this data should be merged with scientific data and made accessible to all. Calibration should also be considered to ensure the wide and accurate use of ocean acoustic data.

There should also be regional academic centers for handling acoustic data that are tailored to each region's needs. In some areas, the need may be limited to data clearinghouse and archival services; in other regions, there may be a need for a regional center to process data for management interests (see discussion under Question #2 above).

**Question #4. What are the technical challenges for long-term acoustic monitoring of remote areas, especially interactions with ocean observing systems?**

The main technical challenges include:

- supplying adequate power
- preventing biofouling of the sensors. While less of an issue than for optical sensors, it can still create some challenges (e.g., fish scraping algae off hydrophones and communities such as shrimps, amphipods, and crabs taking up residence on the hydrophone-based system)
- supplying adequate bandwidth
- limited disk space for data archival



- interpretation of ocean noises requires more ecological understanding

Integration of passive acoustics monitoring and water quality monitoring may be a good approach to increasing the use of passive acoustics. However, correlations need development, and scientists and managers need more interactions with regional ocean observing systems.

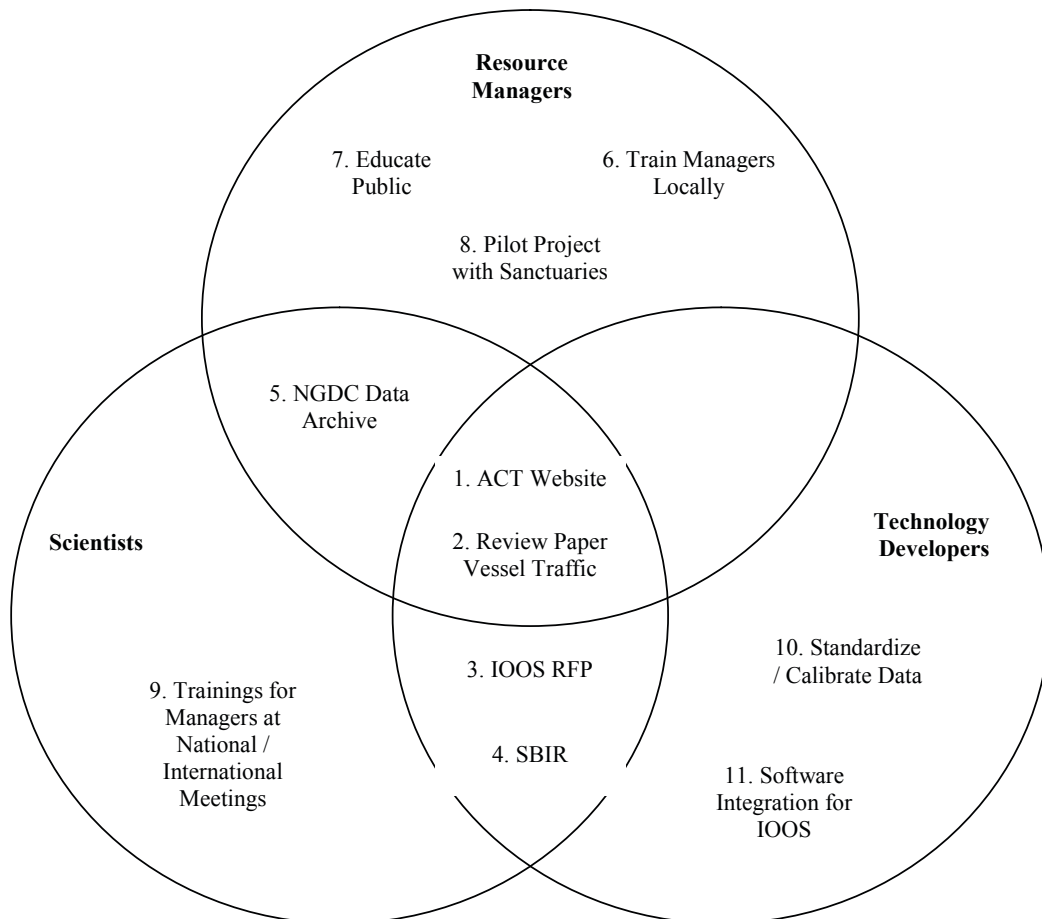
## RECOMMENDATIONS

Participants participated in a facilitated brainstorm to develop recommendations. The brainstorm was condensed into 18 recommendations. Each participant was given six stickers to vote for their top needs. The recommendations are listed below in order of decreasing total number of votes.

1. ACT should enhance their website to include specific information for passive acoustics, such as contact lists for each sector, needs of resource managers, links to partner efforts (e.g., Acoustic Society of America (ASA)), and forums to encourage leveraging and collaboration.
2. Several participants should write a review paper on using acoustics for vessel detection. The paper should be published in a popular magazine and should be summarized into a handout for resource managers.
3. ACT should provide workshop recommendations to funding agencies and program such as IOOS so that RFPs might be created to coordinate basic science studies with routine data collection by managers. IOOS should initially focus on vessel detection but allow the data to be collected and used for ecological applications.
4. ACT should provide workshop recommendations to NOAA and DOD that the Small Business Innovation Research (SBIR) Program might include a priority topic to encourage commercialization of passive acoustics. Specifications for two products should be developed: one specialized for remote users and one targeted to specific biological interactions.
5. The National Geophysical Data Center (NGDC) should archive acoustic environmental data.
6. Passive acoustic training should be developed for managers, including manuals, Frequently Asked Questions handouts, and localized training workshops. Passive acoustic training workshops for resource managers might take place in conjunction with national or international conferences and meetings.
7. Public facilities, such as aquaria should be encouraged to educate the public on ocean sounds. ACT can help develop a primer to distribute to outreach personnel at public facilities.
8. The NOAA National Marine Sanctuaries Program should conduct, or at least encourage, passive acoustic pilot demonstration projects within the sanctuaries.
9. The passive acoustics community, including all workshop participants, should adopt the standardized data format being developed by the ASA Calibration Subcommittee.

10. Technology developers and the observing community should ensure that passive acoustic software systems are integrated observing efforts.
11. DOD should allow research scientists to have access to DOD-produced acoustic sensor training programs. Workshop participant Blair Kipple will make initial inquiry.
12. ACT should disseminate passive acoustics information internationally through partnerships with programs like the International Conference on Computational and Experimental Engineering and Sciences and the Census of Marine Life.
13. Workshop participants should get involved with ASA.
14. Resource managers should utilize central data processing by expert groups when they lack capacity to analyze and interpret passive acoustic data.

Each sector was given a different color sticker to vote. Each sector had a similar but not equivalent number of voters. The top six recommendations for each sector are shown below, illustrating consensus and disagreement in priorities.



**SUMMARY**

The workshop was designed to make strategic recommendations for future development and collaborative programs that use passive acoustic tools for scientific investigation and resource management. This objective was achieved, as several strategic recommendations emerged that can take the field to the next level. The participants left feeling more united as a community and empowered with tangible objectives for collaboration. The following three take-home messages prevailed:

1. Hydrophone hardware and signal processing have been well developed by the military, and technological development is not limited to monitoring remote marine areas. Stronger partnerships need to be built between the military and other users (academics and resource managers) to facilitate the transfer of knowledge.
2. Resource managers have a strong need to monitor vessels. Available technologies and data analysis programs are adequate to meet their needs and are relatively affordable. Since management agencies often lack the local capacity to deploy and analyze data from instrumentation, collaboration with academic groups is encouraged.
3. Further scientific investigation is required to correlate sounds with biological and ecological events and cycles. Passive acoustic monitoring is not yet capable of monitoring ecosystem health. Scientists and managers should collaborate on larger-scale projects to leverage funds and quicken progress toward this application.

ACT workshops all feature different technologies but have recurring themes that also surfaced here. Standardization of methods and data storage continues to be important. Data archival at the national level would be beneficial. The technology developers have open ears for the users and want to hear what the managers require; however, the managers are often unsure of their requirements until they understand the range of what is available. Cross-sector communication and collaboration is ever important.

Many of the workshop recommendations are low-cost and can be executed relatively quickly. ACT currently has the ability to facilitate measurable progress in the field. With the continued support and hard work of workshop participants, ACT plans to follow-up on this workshop by implementing as many of the workshop recommendations as possible based on available resources and prioritization by the ACT Board of Directors and Stakeholders Council.

**APPENDIX A. LIST OF ATTENDEES**

Wayne Andrew  
Helens Reef, Palau  
helenreef@palaunet.com

Rusty Brainard  
Division Chief  
NOAA Fisheries, Coral Reef Ecosystem Division  
1125-B Ala Moana Blvd  
Honolulu, HI, 96814  
(808) 983-3737  
rusty.brainard@noaa.gov

Sean Corson  
Field Operations Coordinator  
NOAA, NWHI Monument  
6600 Kalaniana'ole Hwy, Ste. 300,  
Honolulu, HI 96821  
397-2660 ext. 225  
sean.corson@noaa.gov

Kathy Frost  
Alaska Beluga Whale Committee  
73-4388 Pa'iaha Street  
Kailua-Kona, HI 96740-9311  
(808) 325-6885  
frostlow@ptialaska.net

Dave Johnston  
NOAA  
dave.johnston@noaa.gov

Randy Kosaki  
Research Coordinator  
NOAA, NWHI Monument  
6600 Kalaniana'ole Hwy, Ste. 300  
Honolulu, HI 96821  
397-2660 ext. 243  
randall.kosaki@noaa.gov

Greg Moretti  
Marine Protected Areas Systems Specialist  
CNMI Division of Fish and Wildlife  
PO Box 10007  
Saipan MP 96950  
670-234-0942  
moretti@gmail.com

Dan Polhemus  
Administrator  
Hawaii Division of Aquatic Resources  
1151 Punchbowl Street, Room 330  
Honolulu, HI 96813  
808-587-0100  
dan.a.polhemus@hawaii.gov

Erik Stabenau  
Supervisory Hydrologist  
Everglades National Park  
40001 State Road 9336  
Homestead, FL 33033  
305.242.7818  
erik\_stabenau@nps.gov

Don Baltz  
Professor  
Department of Oceanography and Coastal Sciences,  
Louisiana State University  
Baton Rouge, LA 70803-7503  
225-578-6512  
dbaltz@lsu.edu

Thomas Grothues  
Research Assistant Professor  
Rutgers University Marine Field Station  
800 c/o 132 Great Bay Blvd.  
Tuckerton, NJ 08087  
(609) 296-5260 x262  
grothues@marine.rutgers.edu

John Hildebrand  
Professor  
Scripps Institute of Oceanography  
Ritter Hall 200C  
8635 Discovery Way  
La Jolla, CA 92093-0205  
(858) 534-4069  
jhildebrand@ucsd.edu

**APPENDIX A. LIST OF ATTENDEES (CONTINUED)**

Bob Lauth  
Supervisory Research Fishery Biologist  
Bering Sea Groundfish Assessment Program DOC/  
NOAA/NMFS/Alaska Fisheries Science Center  
RACE Division  
7600 Sand Point Way NE  
Seattle, WA 98155-0070  
(206) 526-4121  
bob.lauth@noaa.gov

Phil Lobel  
Professor  
Dept. of Biology, Boston University  
5 Cummington Street  
Boston, Massachusetts 02215  
617 358-4586  
plobel@bu.edu

Joe Luczkovich  
Dept. of Biology, Institute for Coastal and Marine Resources, East Carolina University  
383 Flanagan Building, East Carolina University  
Greenville, NC 27858  
252-328-9402  
luczkovichj@ecu.edu

Rodney Rountree  
Marine Ecology and Technology Applications  
23 Joshua Lane  
Waquoit, MA 02536  
(508) 540-6970  
rrountree@fishecology.org

Orson Smith  
Professor and Chair  
Civil Engineering Department  
University of Alaska at Anchorage  
3211 Providence Dr.  
Anchorage, AK 99508  
907-786-1910  
afops@uaa.alaska.edu

Mark Sprague  
Associate Professor  
Dept. of Physics, East Carolina University  
Greenville, NC 27858  
252-328-1862  
spraguem@ecu.edu

George Woodman  
Director  
Teng Hoi Conservation Organization  
P.O. Box No. 96421  
Tsim Sha Tsui Post Office  
Kowloon Hong Kong  
852 3618 4515  
george@tenghoi.org

David Demer  
Leader, Advanced Survey Technologies Program  
NOAA, Southwest Fisheries Science Center  
8604 La Jolla Shores Drive  
La Jolla, CA, U.S.A., 92037  
(858) 546-5603  
david.demer@noaa.gov

Grant Gilmore  
Senior Scientist  
Estuarine, Coastal and Ocean Science, Inc.  
5920 First St. SW  
Vero Beach, FL 32968  
772/562-9156  
Rggilmorej@aol.com

Cliff Goudey  
Director  
Massachusetts Institute of Technology  
Center for Fisheries Engineering Research  
MIT Bldg. NE20-376  
3 Cambridge Center  
Cambridge, MA 02139 USA  
617-253-7079  
cgoudey@mit.edu

Rick Hess  
Technical Director  
National Defense Center of Excellence  
for Research in Ocean Sciences  
737 Bishop St, Suite 3030  
Honolulu, HI 96813  
808 587-5500  
rickh@ceros.org

**APPENDIX A. LIST OF ATTENDEES (CONTINUED)**

Jim Hino  
Chief Scientist  
Referentia Systems Inc  
550 Paiea St. Suite 236  
Honolulu, HI 96819  
(808) 423-1900 x146  
jhino@referentia.com

Blair Kipple  
Senior Engineer  
Naval Surface Warfare Center - Bremerton Detachment  
530 Farragut Ave  
Bremerton WA 98314  
(360)476-4612  
blair.kipple@navy.mil

Kevin Kremeyer  
VP of Research  
PM & AM Research  
1665 E. 18th Street, suite 112  
Tucson, AZ 85719  
(520) 903-2345  
kremeyer@physics-math.com

Marc Lammers  
Hawaii Institute of Marine Biology  
808-375-0010  
lammers@hawaii.edu

Joe Olson  
Owner  
Cetacean Research Technology  
PO Box 70186  
Seattle, Washington 98127-0186  
(206) 297-1310  
crt@cetaceanresearch.com

Zachary Upton  
Senior Scientist  
BBN Technologies  
1300 N. 17th Street Suite 400  
Arlington, VA 22209  
(703) 284-1333  
zach@bbn.com

Marlin Atkinson  
Hawaii-Pacific Partner of ACT  
Hawaii Institute of Marine Biology  
PO Box 1346  
Kaneohe HI 96744 USA  
808-235-2224  
mja@hawaii.edu

Shannon Atkinson  
Alaska Partner of ACT  
Alaska Sea Life Center  
301 Railway Ave. POB 1329  
Seward, AK 99664-1329  
(907)224-6346  
shannon\_atkinson@alaskasealife.org

Melissa Bos  
Hawaii-Pacific Coordinator of ACT  
Hawaii Institute of Marine Biology  
PO Box 1346  
Kaneohe HI 96744 USA  
808-235-2224  
mbos@hawaii.edu

Jessica Ryan  
Alaska Sea Life Center  
301 Railway Ave. POB 1329  
Seward, AK 99664-1329  
jessica\_ryan@alaskasealife.org

Dan Schar  
Hawaii-Pacific ACT Technical Coordinator  
Hawaii Institute of Marine Biology  
PO Box 1346  
Kaneohe HI 96744 USA  
808-235-2224  
schar@hawaii.edu

Angie Steeves  
Research Administrative Assistant  
Alaska Sea Life Center  
301 Railway Ave. POB 1329  
Seward, AK 99664-1329  
907-224-6345  
angies@alaskasealife.org

**APPENDIX A. LIST OF ATTENDEES (CONTINUED)**

**APPENDIX B: PARTICIPANT SUMMARIES**

Participants were asked to submit summaries prior to the start of the workshop. Directions for preparation were different for each sector and included below. Summaries are included alphabetically by sector.

**Resource Managers**

Resource Managers were asked to provide a 250-word summary that describes:

- the resources that they manage
- the challenges they face that acoustic monitoring might address
- current monitoring program
- past use of acoustic monitoring (if applicable)
- needs for tool development

**Andrew, Wayne**  
**Helen Reef Resource Management Program**  
**Republic of Palau**

Helen Reef is a large, biologically diverse atoll located in the remote Southwest Islands of Palau. Helen Reef is an important sea turtle nesting site and an over-flight refuge and nesting site for several species of seabirds. It is the traditional fishing ground for the people of Hatohobei. In recent decades, foreign poaching and over-fishing have threatened the biological health of the Reef.

In response to these challenges, the people and State of Hatohobei made attempts to protect and better manage the Reef's resources. The Hatohobei Community have established a community-based management program that employs six conservation officers who do the site surveillance and deterrence program. The project staffs also organize an annual community resource surveying effort at the site.

Despite the success of the conservation efforts, it also faces many challenges, such the size and remoteness of the site and the cost of providing 100% surveillance at the site. HRRMP hopes to investigate the role that acoustics monitoring can play in facing these challenges. For example, there is currently a 24/7 presence on Helen Island where conservations officers provide surveillance with the assistant of a small radar station. However, the radar equipment can run into technical problems, which are difficult to fix since parts and expertise are unavailable because of the remoteness of the Island. The Program is interested in knowing whether Acoustics monitoring techniques can be a complement, or even a replacement, to the radar system. Also, in efforts to reduce cost, the Program is looking to move the station to Tobi Island, 40kms away. We are interested in knowing whether Acoustics monitoring can assist monitoring efforts from such distances.



**Frost, Kathy**  
**Alaska Beluga Whale Committee**  
**Alaska, U.S.A.**

The Alaska Beluga Whale Committee (ABWC), in cooperation with NOAA/NMFS, manages beluga whales in northern Alaska. Information about abundance and activities that may affect habitat quality is important for management. Historically, aerial surveys of summer concentration areas have been used to determine abundance, with survey timing determined by our knowledge about seasonal movements. This has worked quite well in Bristol Bay and Norton Sound. However, since the early 1990s, ABWC researchers have been unable to adequately assess population size for the eastern Chukchi Sea stock. Recent changes in ice break-up in spring seem to have changed the chronology of beluga arrival and have made it difficult to predict when and where belugas can best be counted. Thus, we currently have no good abundance estimate for Chukchi Sea belugas.

Autonomous passive acoustic recorders attached to oceanographic buoy arrays deployed at the mouth of Kotzebue Sound and off Omalik Lagoon (about 40 miles southwest of Point Lay) could assist us. The acoustic packages would monitor beluga vocalizations and allow us to document the arrival and presence of belugas in these areas. Real-time access to the acoustic data would allow us to plan aerial surveys and/or design better methods to assess abundance. In addition to documenting seasonal occurrence, the acoustics data could be used in conjunction with oceanographic data from the same buoy arrays to model effects of environmental variability on beluga occurrence. Acoustic data would also be valuable for evaluating the possible effects of human activities and could provide a way to monitor changes in beluga distribution and movements that are expected to occur with climate warming.

**Kosaki, Randall**  
**NOAA Northwestern Hawaiian Islands Marine National Monument**  
**Hawaii, U.S.A.**

The Northwestern Hawaiian Islands Marine National Monument is co-managed by NOAA, the State of Hawaii DLNR, and the U.S. Fish and Wildlife Service. The Monument encompasses 140,000 square miles of marine habitat, including shallow coral reefs, deep reef slopes, seamounts, pelagic waters, and abyssal habitats. To characterize the marine fauna of these habitats on a large geographic scale is a daunting task. This challenge is compounded by the remote nature of the region and seasonal weather considerations. Access to most areas of the Monument requires large research vessels, and *in situ* monitoring activities by divers or other methods requiring a manned presence have historically been limited to a late spring through early fall weather window. The possibility of large northwest swells and inclement weather virtually preclude field activities for almost half the year.

Acoustic technology has the potential to address many of these logistical challenges to characterization and monitoring. Initial information needs by managers include basic presence/absence information on all taxa of organisms. Acoustic characterizations would be especially useful for groups of organisms that are characterized by species-specific acoustic signatures, such as marine mammals. While many coral reef organisms are known to produce sounds, more research may be

needed to establish the specificity required to generate presence-absence information at the species level.

The next level of characterization of interest to managers may include monitoring (i.e. repeated characterizations over time) in order to identify temporal cycles or long-term trends in the abundance, distribution, or activities of marine organisms. An understanding of the behavioral and ecological contexts for sound production will be key to creating products of value to managers. Real-time data acquisition and analysis is not initially a requirement. The ability to record several months of data would allow for some monitoring or data collection to occur during seasons or periods when maintaining a manned presence is not practical.

Finally, acoustic technology deployed for purposes of biological characterization or monitoring may yield spin-off information of great value to managers, such as data on vessel traffic and other human activities. The greatest need for real-time access to acoustic data may indeed come from enforcement needs rather than biology.

**Moretti, Greg**

**Division of Fish and Wildlife**

**Saipan, Commonwealth of the Northern Mariana Islands**

The 290 km long Mariana Islands Archipelago encompasses 14 islands of the U.S. Commonwealth of the Northern Mariana Islands (CNMI), the U.S. Territory of Guam, and numerous offshore banks. The southern arc islands have the oldest and most developed reefs in the CNMI, which are predominantly located along the western (leeward) sides. The majority of the CNMI's residents live on Rota, Tinian, and Saipan, the capital. *Saipan*, the largest of the Northern Mariana Islands, has a land area of 122 km<sup>2</sup> and is approximately 20 km long and 9 km wide. The island has the most diverse types of coral reefs and associated habitats in the Commonwealth. A fringing and barrier reef system protects the majority of the beaches along the western and coastal plains. The western side of the island is the most populated, and the coral reefs along these areas are negatively affected by human activity.

The DFW Fisheries Research Section established a Marine Sanctuaries Program (MSP) in 1998 and has been surveying MPAs in the CNMI since 1999. The primary goal of the survey is to monitor annual trends in reef fish abundance and diversity. Secondary goals include monitoring changes in benthic habitat composition, macroinvertebrate abundance, and habitat heterogeneity. Using a habitat-based stratified sampling method, data are collected along 25 m by 4 m transects located haphazardly within habitat types.

We have never used acoustic monitoring in the past but are interested in the possibility of using it to monitor vessel activity in the remote reefs of the Northern Islands. Challenges to remote reef management generally include a lack of sustained management presence, lack of continuous enforcement presence, logistics associated with accessing remote locations, and the high cost of surveillance and enforcement of illegal fishing activities. At this time, due to the remote location of the reefs in the CNMI northern islands, documentation of the primary threat to those resources, poaching from international fishing vessels, is limited to observations of apparent damage and abandoned gear seen by scientists during routine biological monitoring and anecdotal evidence

from fishermen. In order to better document the threats associated with poaching from international vessels, we would like to consider the use of acoustic monitoring to better determine the frequency of both legal and illegal fishing activity on the remote reefs of the CNMI.

**Polhemus, Dan**  
**Division of Aquatic Resources (DAR) for the State of Hawaii**  
**Hawaii, U.S.A.**

The DAR, part of the State of Hawaii's Department of Land & Natural Resources, is the primary steward of the State's marine resources from the shoreline to 3 miles offshore, as well as all fresh and estuarine waters in the Hawaiian Archipelago. The DAR employs approximately 95 staff, with a headquarters office in Honolulu and field offices in Hilo, Kona, Maui, Molokai and Kauai. The DAR staff oversee management of a wide array of marine managed areas, including 11 no-take Marine Life Conservation districts protecting such well known sites as Waikiki, Hanauma Bay, Molokini, and Kealahou Bay; 19 marine Fishery Management Areas designed to provide recreational fishing opportunities; 9 fisheries replenishment areas, which constitute no take zones for aquarium collecting; 12 bottomfish restricted fishing areas that serve as refugia and recruitment zones for deep water snappers and groupers; and the Northwest Hawaiian Islands Marine Reserve (now part of the NW Hawaiian Islands Marine National Monument).

Acoustic technology has been an important aspect of monitoring all of the above areas, with particular emphasis in the immediate past on assessing movement patterns of fishes into and out of the Marine Life Conservation Districts in order to determine if boundaries were appropriately delineated. Other acoustic projects have tracked the movement of mullet in and out of the Wailoa River in the Hilo Harbor fishery management area, of bottomfishes on the Maui platform, and of coral reef fishes in the NW Hawaiian Islands.

Most of the deployment of acoustic technology to date has been ad hoc, based on individual projects and their associated funding streams. More recently, DAR has begun to use federal sport fish program funds to develop a more comprehensive network of acoustic receivers in the main Hawaiian Islands, but this program is still in its initial stages.

**Stabenau, Erik**  
**Everglades National Park**  
**Florida, U.S.A.**

I am a resource manager with an interest in assisting in the development of sensors, by deploying them on our network stations, acquiring data, and providing feedback to development. Currently, in our hydrology program at Everglades National Park, we have a team of technicians that maintain ~130 hydrological monitoring stations equipped with stage, conductivity, temperature, and rain sensors delivering data hourly via radio modems or GOES. My training is primarily in ocean optics where, in previous work, I used the available underwater light field to monitor for changes in seagrass turnover rates, the processing of optically active components, and the subsequent delivery of those components into coral reef environments. Generally, optics offered a method of monitoring for ecosystem level changes in the environment, providing the opportunity to interpret variation in more commonly recorded coastal ocean parameters - salinity, temperature and nutrients - in

a new 'light.' Passive acoustics offers an alternative method to approach the same problem, with its own set of strengths and weaknesses. In either case, passive sensors have an inherent advantage of active sensors in many applications due to their lower power requirements and reduced impact on the environment.

During this workshop, I anticipate learning about these systems abilities (1) to differentiate biological signals from boat, rain, and wave related noise in shallow water environments, and (2) to process data on-site in order to compress high resolution broad spectral data into discrete packets that can be transferred through band-width limited telemetry. Specific applications within Everglades National Park may include monitoring for vessel traffic, fish spawning, or changes in the 'background' noise levels that may be indicative of change with respect to the Everglades restoration program.

## **Research Scientists**

Research scientists were asked to provide a 250-word summary that describes:

- their key research programs and goals
- what they are monitoring with passive acoustics
- how they would like to use acoustic monitoring in the future
- needs for tool development

**Baltz, Donald**

**Department of Oceanography and Coastal Sciences, Louisiana State University  
Louisiana, U.S.A.**

### ***Spawning Site Selection by Coastal Fishes in the Northern Gulf of Mexico***

Our goal is to develop basic ecological information on the spawning habitat requirements of soniferous fishes that can be used to study breeding behavior and understand environmental factors that influence spawning success and successful recruitment of early life history stages into nursery habitat. We have used passive acoustics to study spawning of *Cynoscion nebulosus*, *Cynoscion squamipinnis*, and *Pogonias cromis* (Saucier et al. 1992. *Northeast Gulf Science* 12:141-145; Saucier & Baltz 1993. *Environmental Biology of Fishes* 36:257-272; Baltz & Campos 1996. *Revista de Biologia Tropical* 44:743-751). Other important fishes are found in the coastal waters of the northern Gulf of Mexico and around the world, and the spawning requirements of most of them have not been well studied. One reason is that many spawn late in the evening in open waters that are often not safe for small boats. Most notably, red drum (*Sciaenops ocellatus*) spawn in Louisiana's coastal waters amid a dynamic landscape that is experiencing natural and anthropogenic changes, including water management, sea-level rise, canal dredging, industrial development, land loss, shipping, and the effects of fishing. For this and other species, we need to know what ecological conditions along complex environmental gradients are most suitable for spawning so that essential habitats can be identified and managed. Our wish list is topped by a fixed or moveable listening array with overlapping directional capabilities to generate position fixes, computer programs to process fix data, and real-time transmission capabilities to allow relatively small boats to move to aggregation sites for environmental measurements.

**Demer, David**  
**NOAA Southwest Fisheries Science Center**  
**California, U.S.A.**

***Objectives***

The stocks of lingcod and six rockfish species, including four that are important to California anglers and commercial fishermen (bocaccio, canary rockfish, widow rockfish, and cowcod), are estimated at or below 25% of their pristine levels and have been declared over fished by the Pacific Fisheries Management Council. In response, two marine conservation areas were recently created in the Southern California Bight (SCB), and an active-acoustic-optical survey method (AOS) was developed for mapping rockfish distributions and estimating their abundances. Between bi-annual AOS surveys, fishing activities and possibly dynamics in rockfish abundance and spawning could be efficiently monitored using passive acoustic techniques. All rockfish are physiologically capable of producing sound, and Love *et al.* (2002) suggest that they do so during courtship. From vessels and fish, low-frequency tones can be expected; *Sebastes* may also produce low-frequency stridulatory sounds.

***Technology Needed***

Passive acoustic loggers to continuously monitor fishing activities and rockfish sounds in the SCB.

***Requirements***

Self-contained passive acoustic loggers; BW=10 Hz to 1 kHz; either deployable on the seafloor or from an autonomous underwater vehicle (AUV); depth to 500 m; 1-12 month operation; retrievable on-demand.

***Reference***

Love, M. S., M. Yoklavich and L. Thorsteinson (2002), The rockfishes of the northeast Pacific. Berkely and Los Angeles, CA, University of California Press.

**Grothues, Thomas**  
**Rutgers University**  
**New Jersey, U.S.A.**

I am a research scientist interested in describing the landscape and oceanographic parameters that influence the diel and seasonal spawning patterns of soniferous fishes on the temperate US Middle Atlantic Coast, a region of broad, gently sloping shelf dominated by soft substrate. The region experiences the highest annual temperature range of any oceanographic province, but is also highly dynamic on the shorter scale, such as influenced by upwelling and hypoxia. Thus, most species in the area are migratory and not necessarily tied to specific benthic features. Colleague David Mann (USF) and I have demonstrated the potential for passive acoustics to monitoring spawning-related soniferous activity continuously across the scale from interannual to minutes and over kilometers using a realtime connection with a cabled underwater instrument host, the Long-term Ecological Observatory at 15 m depth (LEO-15) off of the New Jersey coast. Our work couples acoustic monitoring with egg production surveys and real time, depth-discreet data on temperature, salinity,

tide, wave height, turbidity, incident light, and current vector, and with additional recordings over a kilometers-scale logger array. Cabling also facilitates public outreach regarding this little known facet of fish research and provides real-time access via internet for decision making regarding re-active sampling for eggs or adult trawl surveys. Challenges remain for the compression, storage, and treatment of voluminous data sets and the high-fidelity of species discrimination. The recent change in node architecture also presented challenges in moving from analog to digital only (fiber-optic) sound re-transmission from the node to the shore-side processor.

**Hildebrand, John**

**Scripps Institution of Oceanography, University of California at San Diego  
California, U.S.A.**

***Acoustic Monitoring of Marine Mammals and Ambient Noise***

Acoustic monitoring is complimentary to visual approaches for the study of marine mammal populations. When acoustic and visual techniques are compared, they often reveal different aspects (behavioral, spatial, or temporal) of the population under study. Acoustic Recording Packages (ARPs) have been deployed continuously for up to one year to study baleen whale calls at low frequencies (e.g., 1000 Hz). Recently, High-frequency Acoustic Recording Packages (HARPs) have allowed the study of odontocetes. Current HARP capabilities are for sampling rates up to 200 KHz, and data storage up to 1920 Gbytes, which allows for 55 days of continuous sampling. Longer deployment times are possible using intermittent sampling (e.g., 330 days at 1/6 duty cycle). Long-term acoustic recordings reveal that odontocete clicks (impulsive calls generally at frequencies above 20 kHz) are helpful in species identification. Examples of data from several different regions are presented, along with techniques for data analysis.

The characteristics of ambient noise from commercial shipping and whale watching boats are presented. Ambient noise in the North Pacific basin has increased at a rate of about 3 dB per decade for at least the past four decades. Repeat ambient noise measurements at the San Nicolas SOSUS array site (off shore southern California) reveal about 12 dB of increased noise in the low frequency band (10-80 Hz) between the early 1960s and the early 2000s. These data suggest that both, more commercial ships and increased noise from individual ships, have contributed to increases in ambient noise.

**Kipple, Blair**

**Naval Surface Warfare Center, Bremerton, WA**

***Research Program***

Glacier Bay National Park Underwater Acoustics.

***Goals***

Characterize the underwater acoustic environment of lower Glacier Bay and assess the influence of vessel activity on the acoustic environment.

### **Monitoring**

Collected hourly acoustic samples from May 2000 through present to determine acoustic contributions of natural and manmade sources of underwater sound to the overall soundscape of lower Glacier Bay, including natural surface generated noise from wind and rain, frequency of occurrence of marine mammal sounds (primarily humpback whales and killer whales), and noise from recreational and commercial vessels. Acoustic sample data were archived in a database. Range of levels and dominant frequencies of natural and manmade sources were established. Frequency of occurrence of vessel sounds, marine mammal sounds, and vessel-free conditions were established.

### **Future Use**

Continued monitoring of Glacier Bay, particularly for marine mammal monitoring and assessment of impacts of changes in levels and types of vessel activity.

### **Needs for Tool Development**

Primary need is for automated acoustic sample analysis tool.

### **Lauth, Robert**

**Bering Sea Groundfish Assessment Program DOC/NOAA/NMFS/Alaska Fisheries Science Center  
Washington, U.S.A.**

The mission of the Alaska Fisheries Science Center (AFSC) is to generate the scientific information and analysis necessary for the conservation, management, and utilization of the region's living marine resources. My primary role as a research scientist in the Groundfish Assessment Program is to conduct research and to plan and carry out Alaska bottom trawl surveys. Research and survey results are used as key inputs to stock assessment analyses used by the North Pacific Fishery Management Council (NPFMC) for various commercial groundfishes, such as walleye pollock (*Theragra chalcogramma*), Pacific cod (*Gadus macrocephalus*), Atka mackerel (*Pleurogrammus monopterygius*), rockfishes (*Sebastes* spp.), and flatfishes (Pleuronectidae). Under the federally mandated ecosystem management approach, increasingly more detailed information about the structure and function of the marine ecosystem is needed. I believe passive fish acoustics has management applications, but its utility for Alaskan marine fishes is currently not a priority. I am collaborating with other researchers to advance the science of fish vocalizations in Alaska by developing a basic library of sounds. I am also interested in learning how marine fishes utilize their habitat spatially and temporally during different life history stages, especially when they aggregate during spawning periods. I am collaborating with the Alaska SeaLife Center in Seward, Alaska to conduct laboratory experiments to determine if captive Atka mackerel and walleye pollock produce vocalizations during spawning or nesting periods. The AFSC's Fisheries Behavioral Ecology Program is currently rearing Pacific cod at their Newport, Oregon Laboratory that we plan to use for the same purpose when they reach sexual maturity. The Newport Laboratory will also be helping with an *in situ* study around Kodiak Island, Alaska to determine if spawning aggregations of Pacific cod produce vocalizations. My current needs include signal processing software and time-efficient methods for identifying and extracting data from large sound files. I am also interested in lightweight and streamlined passive acoustic recording devices for deployment with a

portable towed drop camera. I would also like examples or case histories from other regions where passive acoustics is being used in resource management of a commercially exploited species.

**Lobel, Phillip**  
**Boston University**  
**Massachusetts, U.S.A.**

The goal of our research is to understand the biological function and evolution of sound production in fishes and to apply this knowledge to conservation and fisheries management. Specifically, we are determining if different species produce specific sounds exclusively with particular behavior. For details see 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 and Lobel, P. S. 2002. *Diversity of fish spawning sounds and the application of passive acoustic monitoring*. Bioacoustics 12:286-289.

We are engaged in the following activities:

- Developing methods, tools, and diving techniques for recording wild fishes underwater.
- Establishing the statistical patterns of fish sounds as per species and behavior
- The invention and continued development of the “spawn-o-meter,” for passive acoustic monitoring of fish mating sounds.

We are using passive acoustics to study and monitor:

- The bioacoustics of damselfish, e.g., *Dascyllus* spp (*D. albisella* in Hawaii and *D. trimaculatus* elsewhere in the Pacific) as key species for monitoring coral reef health and fish reproductive patterns. We conducted extensive field recordings and spawn-o-meter monitoring at Johnston Atoll (1992-2003).
- Fish mating sounds to determine spawning patterns and correlation to physical oceanographic variables.
- Boat noise in marine protected areas to assess disturbance to fishes and as a way to quantify illegal fishing especially at night (in Belize at spawning aggregation sites).

Needs for future tool development:

1. Adaptive noise filtering of background sounds.
2. Acoustic-video database management and archive software
3. Data transmission from underwater recording units including uplink to a surface boat and, for remote area deployments, uplink to satellite.

**Luczkovich, Joseph**  
**East Carolina University**  
**North Carolina, U.S.A.**

***Passive Acoustics and the Behavior of Fishes***

Using passive acoustic survey methods (hydrophones and automated recorders), Mark Sprague and I have uncovered patterns of habitat use and sound production that are tied to spawning activi-



ties of fishes in the drum and croaker family (Sciaenidae) with minimal impact to the population. We have published a series of papers and reports that describe the spawning habitats of red drum, *Sciaenops ocellatus*, weakfish, *Cynoscion regalis*, spotted seatrout, *Cynoscion nebulosus*, and silver perch, *Bairdiella chrysoura*, all of which use high-salinity areas near the inlets along NC Outer Banks (Luczkovich et al. 1999; Sprague et al. 2000, Luczkovich and Sprague 2002). We discovered that silver perch, a fish that bottlenose dolphins *Tursiops truncatus* consume, minimizes its risk of predation by becoming silent when sounds of the dolphin are recorded in the vicinity or are experimentally played back (Luczkovich et al. 2000). We have used a remotely operated vehicle (ROV) and calibrated hydrophone system to measure the sound pressure levels of silver perch in situ (Sprague and Luczkovich 2004), a measurement that has been lacking for most fishes that make sound. In the future, additional measurements of sound source and frequency levels, background sound levels (natural and anthropogenic), and sounds associated with different species in situ and in captivity are needed. Such measurements made in conjunction with direct observation of spawning behavior and habitat use will help biologists and acousticians understand and model the complex acoustic environment in shallow water and will lead to seasonal habitat use data and population estimates using acoustics.

**Rountree, Rodney**

**Marine Ecology and Technology Applications, Inc., and University of Massachusetts at Amherst  
Massachusetts, U.S.A.**

I have been working with colleagues around the world to develop the science of passive acoustics applications to fisheries and marine exploration for the past seven years. I co-organized an international workshop on this subject in 2002 and a special Symposium at the American Fisheries Society meeting in 2003. I have published proceedings from these workshops and recently published a comprehensive review of the potential of passive acoustics and a review of the software and hardware developments needed to grow the field. My personal research is varied and ranges from a survey of soniferous marine fishes of Massachusetts to the first field recordings of haddock and cod sounds from the western Atlantic Ocean. In this study, my colleagues and I have worked with commercial fishermen to monitor underwater sounds on the fishing grounds of the Gulf of Maine. My colleagues and I also recently conducted a pilot survey of the Hudson River system, which is the first such survey for any major freshwater system in North America. I maintain an active web site, [www.fishecology.org](http://www.fishecology.org), where much of this information is summarized.

**Smith, Orson**

**Department of Civil Engineering School of Engineering, University of Alaska Anchorage  
Alaska, U.S.A.**

The majority of my experience with acoustics involves engineering-oriented applications of single- and multi-beam fathometers, side-scan sonar, and acoustic Doppler current profilers. I have for over 30 years used equipment of these types from many of the major vendors. I currently possess a Ross Laboratories 200 kHz single-narrow-beam hydrographic survey system whose primary use is for teaching undergraduate and graduate students. I also possess a 1.5 MHz Sontek acoustic Doppler system that can be configured for current profiling or for directional wave measurement, and I have used it for both.

My purpose for attending the ACT workshop is to learn more of the technology and applications of passive acoustics for possible use in Resurrection Bay and the northern Gulf of Alaska through programs of the Alaska Sea Life Center and the Alaska Ocean Observing System.

Marine mammals and other ocean species are of great importance and considerable concern in Alaska, and passive acoustics are reported as an effective monitoring tool in the right circumstances. I would like to know enough at the end of the workshop to make choices among acoustic systems and alternative deployments for the sake of monitoring activities of marine mammals in Alaska waters. Other applications are also of interest to me, such as monitoring the frequency and intensity of vessel traffic and other human intervention in areas of marine mammal concentration.

**Sprague, Mark W.**  
**Department of Physics, East Carolina University**  
**North Carolina, U.S.A.**

### ***Research***

My research with Joseph Luczkovich focuses on the production, propagation, and detection of sound by organisms in the marine environment.

- Using hydroacoustic surveys to identify critical habitat
- Physical modeling of the fish sound production mechanism
- Shallow water propagation of transient sounds (i.e., fish calls)
- Using fish sound recordings to estimate the distributions and numbers of calling fish
- Acoustic competition and predator-prey interactions
- Relationship between physical properties (i.e., temperature, salinity, DO content, turbidity, current, etc.) and acoustic activity of fishes.
- Development of remote passive acoustics data recorder to record sound and other water properties (see the technology developer summary on this device)

### ***Passive Acoustic Monitoring***

- We are monitoring acoustic activity in Pamlico Sound, NC to determine the relationships between fish acoustic activity (mostly Sciaenidae) and water quality properties, as well as benthic transport activity.
- Our data collecting sonobuoys were deployed on a research cruise in the Phoenix and Line Islands to monitor acoustic activity during 24-hour deployments.

### ***Future Use of Acoustic Monitoring***

- Record and telemetry data at multiple remote locations
- Remote acoustic arrays

### ***Tool Development Needs***

- Ability for a recorder to be deployed for an extended period (> 1 month)
- Ability to remotely connect to recorder in the field and change sampling parameters
- Recorder with flexible telemetry system (radio, mobile phone, satellite)

- Telemetry digested data including species identification
- Pattern-based sampling protocol

**Woodman, George**  
**Teng Hoi Conservation Organization**  
**Hong Kong**

THCO was established in 2004 as a non-profit organization in Hong Kong with the principal aims of developing and implementing technology to detect underwater explosions caused by fish bombs. Fish blasting is a widespread practice in southeast Asia, and there are many reports of occurrences elsewhere (such as East Africa).

Our team has been using acoustic monitoring technology to listen to fish bombs since 1999. The key goals of the research are:

- To record and analyze acoustic signals arising from explosions and determine the direction of propagation.
- To develop filtering systems that can reliably reject background noise events (principally arising from snapping shrimp).

Directionality is determined by time of arrival analysis of the signal at an array of hydrophones (the separation is typically 1 m). Signal analysis incorporates Joint Time Frequency Domain analysis to characterize events and reject background noise.

The system now operates in real time and a system has been temporarily installed at the WWF Hong Kong Marine Life Centre as a development trial in collaboration with WWF Hong Kong. The centre is located in a marine park in the territory of Hong Kong in a sheltered bay that can monitor an open sea area up to 17 km distance (to the coastline of mainland China) and spanning around 25° to the north. The latest results of the monitoring work will be presented at the workshop.

Future development is focused on development of self-contained submersible data buoys containing the required hydrophones, electronic compasses and digitizing and processing hardware. These will be piloted in Sabah, Malaysia in collaboration the government of Sabah, University Malaysia Sabah and with UNEP to evaluate the directional accuracy of the system and application for law enforcement.

**Upton, Zachary**  
**BBN Technologies**  
**Virginia, U.S.A.**

***Research Scientist Summary***

BBN is involved in a number of passive acoustic monitoring programs. For example, some of our work is focused on monitoring the Earth's oceans for nuclear explosions. Our primary goal is to use our expertise in hydroacoustics, propagation models, and data analysis to sort out all of the things that we see in these signals, and to develop algorithms and software that will allow monitoring systems to discriminate a nuclear test from all of the other signals that the hydrophones record.

These signals include earthquakes, volcanoes, wildlife, vehicles, and other man-made and natural sources.

BBN also has research programs at BBN that involve passive acoustic monitoring for a number of goals including anti-submarine warfare and submarine crew training. We have developed signal processing algorithms for passive detection, classification, localization and tracking of moving targets in noisy environments. BBN has leveraged these algorithms and processes and applied them to the nuclear monitoring efforts discussed above.

BBN has programs devoted to automatic classification of signals. In most cases, this has been focused on classifying vehicle signatures from other noises, but we have recently begun to look at using these tools to classify marine mammal signatures.

In the future, I am interested in how all of this research can be applied to different areas and different media. This workshop's goal of passively monitoring wildlife on the Hawaiian Island Chain is just one of the many possibilities. There are many applications of detection, localization, classification and tracking here. Can we use acoustics to classify marine mammals by species and count them?

## **Technology Developers**

Technology Developers were asked to provide a one-page document that describes their tool(s) including:

- parameters it measures (specifically focused on vessels or organisms?)
- specifications like range, frequency, etc.
- required gear like computer, software, etc.
- cost
- examples of how it has been used
- purchasing information

They were also asked to prepare a 100-word statement about what information they need from the technology users (scientists and managers) to guide future development.

**Demer, David**  
**NOAA Southwest Fisheries Science Center**  
**California, U.S.A.**

### ***Measurements and Uses***

AST has developed instrumentation packages and made passive acoustic measurements of fisheries survey vessels, marine mammals, and fish. Instrumentation has ranged from the use of surplus sonobuoys to measure ambient noise and animal vocalizations in the Southern Ocean; to lab-instruments for measuring fish sounds in tanks and pens; to buoy-based hydrophone arrays for characterizing radiated ship noise; to broad bandwidth hydrophone arrays for measuring multi-scattered fields in reverberant tanks.

### ***Specifications***

Detection ranges have varied from centimeters to tens of kilometers. Frequencies have ranged from 10 Hz to 500 kHz.

### ***Components (e.g.)***

Components of bench systems typically include:

- Hydrophones: ITC 1032, 1042, and 1001B; and Reson TC4013
- Pre-amplifiers: Stanford Research SR570
- Acquisition: National Instruments Daqpad 6070E; GaGe 4 channel 16-bit CompuScope 1610; Edirol sound cards
- Arbitrary waveform generator: Hewlett Packard 33120A; GaGe CompuGen 1100
- Broadband power amplifier: ENI 1140LA; Krohn-Hite 7500
- Software: Matlab, Labview, and C++

### ***Purchasing***

AST develops and employs instrumentation in support of the fisheries research activities at Southwest Fisheries Science Center and other parts of the National Marine Fisheries Service and NOAA. Additionally, AST frequently collaborates with researchers at other institutions (e.g. SIO, UCSC, and St. Andrews University).

### ***Information Needed (e.g.)***

- Acoustic: bandwidth, sampling rate, dynamic range, noise floor, number of channels, and processing requirements
- Mechanical: size, shape, and weight; pressure, materials
- Electrical: power, voltage, current
- Control: manual, autonomous, pre-programmed, remotely controlled
- I/O: serial, cabled or wireless ethernet, USB

### **Gilmore, Grant Estuarine, Coastal and Ocean Science, Inc. Florida, U.S.A.**

All three summary topic areas, technology development, research, and management will be addressed in this summary as all have been intimately associated with my work. As a research scientist at the Harbor Branch Oceanographic Institution (1971-1998), I was involved in the development of autonomous passive acoustic technologies and techniques as part of basic and applied research on fish life history and ecology. During a five year tenure at the Kennedy Space Center (1999-2004), funding from NASA, USGS, NPS and NOAA allowed continuation of passive acoustic biological work, as well as the development of new technologies for deep sea deployment on deep coral reef formations. NASA, NOAA, and Harbor Branch scientists and engineers continue to work with me as a private small business, Estuarine, Coastal and Ocean Science, Inc. (ECOS), in technology and research activities.

The technologies developed include portable and stationary passive acoustic recording systems capable of operating at depths between 1 and 1000 m. We created permanent economical shore based hydrophone sites with telemetry systems and web site access, portable acoustic buoy systems with remote telemetry access for fish spawning/ migration, habitat condition, and human activity studies. Eight different hydrophone types have been used for single phone and multiple phone array deployment strategies using manned surface craft, unmanned surface vehicles (USV), manned submarines, and remotely operated vehicles (ROVs) with varying success. Compatibility with REMUS AUV vehicles was also examined. Recent work has mated high resolution sonar DIDSON with passive acoustic systems to address sound source identification.

Research objectives include sound source classification, quantification, source spatial-temporal mapping, fish spawning activity assessment, marine mammal presence, and determination of human activities, such as boat, ship, diver, fisherman, and rocket launch detection and classification.

State and federal management application studies addressed spatial/temporal distribution of spawning fish relative to natural and manipulated environmental parameters and to determine fish and human use of natural and artificial reef structure. Present management interest emphasizes the use of continual acoustic monitoring of spawning fish relative to changes in water quality and hydrology within estuaries and coral reef condition on the adjacent continental shelf.

**Goudey, Cliff**

**Center for Fisheries Engineering Research, MIT Sea Grant College Program  
Massachusetts, U.S.A.**

Pursuant to a project “The Identification of Cod and Haddock Spawning Habitat Using Passive Acoustics” sponsored by the Northeast Consortium, MIT Sea Grant has developed innovative, low-cost Autonomous Underwater Listening Stations (AULS). The AULS hardware was specifically designed for deployment from commercial fishing vessels for monitoring fishing areas suspected of being spawning areas for cod and haddock.

AULS are built around digital recording devices know as Nomad Jukeboxes by Creative Laboratories. These units were state-of-the-art at the time of the project and employ 10 GB hard drives with two recording channels and selectable sampling rates and gains. At a sampling rate of 11,025 Hz, the unit has a recording duration of approximately 57 hours. This duration and the .wav recording format suited well our nominal 2-day cycle for probe re-deployment.

The Nomad is powered by a pair of 6VDC gel batteries and the electronic components are housed in a pair of 8” polyethylene pipe caps machined to accommodate an O-ring and a band clamp. The design is suited for service in depths less then 100 m based on an initial pressure test failure at 250 m.

An external HTI 96-MIN hydrophone on a 60 cm pigtail mates to a penetrator in the housing top. These hydrophones (High Tech Industries, Gulfport, MS) have built-in preamplifiers that provide a signal level of  $-165$  dB re 1 volt/1  $\mu$ Pa. For isolation purposes, the hydrophone preamp is pow-

ered by a pair of 9V “transistor” batteries. The Nomad’s user-adjustable gain setting can provide up to an additional 20-dB gain.

Hardware costs for these units are less than \$1,000 each. Six AULS probes were built under the NEC-sponsored project. Fourteen additional units, one for each of the NOAA marine sanctuaries, were built to record underwater sounds for use in their k-12 education programs.

To facilitate AULS deployment, galvanized steel bottom mounts were built that weigh 60 pounds and protect the housing from impact by other fishing gear. We have also configured this type of probe as a drop hydrophone. The Nomad and the batteries are contained in a waterproof case (e.g. Pelican) and the hydrophone is provided with a suitable extension cable. This version has been developed using a deepwater trawl float as a housing. This provides us a 1,000m depth capability, but the limited internal geometry required a switch to a battery pack made of 18 NMHi D-cells. The full recording duration of the Nomad was retained.

**Hess, Richard**  
**National Defense Center of Excellence for Research in Ocean Sciences**  
**Hawaii, U.S.A.**

1. **BACKGROUND:** CEROS is a State of Hawaii agency under DBEDT, created in 1992 and funded by Defense appropriations funds, routed through, and with the cooperation of DARPA with a mission to fund ocean and maritime related R&D, through Hawaiian private industry.
2. **PRIORITIES & RESOURCES:** CEROS has funded over 150 projects with an annual budget of \$5-7M. Projects are selected through an annual competitive solicitation process that begins in the fall. The present FY07 process is evaluating 100+ proposals for R&D in the following priority areas:
  - a. Shallow Water Surveillance Technologies, emphasizing innovative approaches to collection, processing, and presentation of information from and about the shallow (continental shelf depth) maritime operational environment.
  - b. Ocean Environmental Preservation, emphasizing innovative system development and demonstrations for ocean environmental sensing, remediation, monitoring, and control.
  - c. New Ocean Platform and Ship Concepts, emphasizing development and demonstration of innovative designs, advanced structures, or improved techniques.
  - d. Ocean Measurement Instrumentation and Ocean Engineering Tools, emphasizing development and demonstration of advanced sensors, innovative undersea systems or facilities, and new techniques for undersea measurement, modeling, prediction, and data exploitation.
  - e. Unique Properties of the Deep Ocean Environment, emphasizing new techniques to identify or exploit unique properties, conditions, materials, products, or potential of the deep ocean for enhanced maritime operational capability; advanced power sources utilizing

batteries, fuel cells, and renewable energy; ocean energy harvesting from waves and currents, gas seeps and gas hydrates, ocean sediments, and water column plankton.

- f. Tooth-to-Tail Logistics and Operations and Maintenance Improvement, emphasizing technologies and techniques for reducing costs relative to the military maritime mission, infrastructure, Naval shipyard productivity and efficiency, etc., driven by the fact 64% of Navy operations costs are for people.
3. CHALLENGES: In selecting appropriate projects, CEROS seeks innovative ideas that are shown to:
    - a. Improve the state of the art of the technology or a capability the technology is serving
    - b. Improve identified capabilities with demonstrated quantifiable metrics
    - c. Lead to a future defense or commercial transition
  4. NEED FOR TOOL DEVELOPMENTS (REQUIREMENTS): CEROS is attending this conference with the aim of identifying and exploring future potential projects to fund that will benefit the State of Hawaii.

**Hino, James**  
**Referentia Systems Inc.**  
**Hawaii, U.S.A.**

Referentia is an applied research company working primarily solutions to challenges for the Department of Defense (DoD). One of Referentia's area of expertise is Anti-Submarine Warfare (ASW), specifically passive algorithm development and situational awareness.

The ASW passive algorithms that have been developed detect, localize, and track submarines based on input from a wide range of sensors, including omni-directional sensors, line arrays, and spherical arrays. The algorithms enhance the signals of interest, as well as remove background clutter. Background clutter includes shipping as well as biologics such as marine mammals, fish, and crustaceans. These algorithms could easily be modified to detect and classify biologics.

The ASW situational awareness tools that have been developed, show sensor coverage of friendly forces and track enemy forces. A high fidelity acoustic propagation loss model called the Scalable Tactical Acoustic Propagation Loss Engine (STAPLE) is used to calculate the probability of detection of an enemy submarine based upon excess signal to noise. STAPLE takes into account surface effects, bottom composition, bathymetry, and sound-velocity profile. Once detected, enemy submarines are tracked with a Kalman filter tracker that is tuned for ASW operations.

The future acoustic challenges for the DoD include:

- Extending detection range in the littorals.
- Extending the range of underwater communications.
- Covertly detecting environmental conditions, such as sediment and sound velocity profile.



**Kipple, Blair**  
**Naval Surface Warfare Center**  
**Washington, U.S.A.**

***Glacier Bay Acoustic Monitoring System***

***Measurement Parameters***

The acoustic monitoring system is geared toward measuring vessel noise and natural sources of underwater ambient noise, including sounds originating from marine life and the sea-surface.

***Specifications***

- Measures absolute face of phone acoustic levels in dB re 1 microPa.
- Frequency range: 10 Hz to 40 kHz
- Collects 30-second duration samples at intervals dictated by user.
- On-demand sample capability.
- Products from each sample: one-third octave spectrum, 10-1000 Hz and 40 Hz - 40 kHz narrowband spectra and spectrograms, wav sound file.
- Also provides continuous real-time audio, and one-third octave, narrowband, and spectrogram displays.
- Sample rate: 88.2 kHz
- Also capable of collecting data continuously.

***Required Equipment***

- Hydrophone (existing system uses an ITC 8215A model hydrophone).
- Hydrophone control unit (DC power supply, signal distribution, supplemental DAT recorder).
- Hydrophone cable (4 conductor plus shield).
- Personal computer (currently Windows XP-Pro based).
- Digital signal analyzer PC board (National Instruments PCI NI-4451).
- Software (system control, data collection, data processing, data archiving, data retrieval).

***Cost***

Hydrophone (\$4100), Cable: (in 2003, approx. \$1 per foot), System: (control unit \$10,000, PC \$1500, PCI card \$3000, etc.), Software (initial support \$3000)

***Applications***

2000 through present: Acoustic monitoring at Glacier Bay National Park, AK to characterize the underwater soundscape and assess the impact of vessels on the acoustic environment. Also used as a marine mammal monitoring tool.

2002 through present: Acoustic monitoring at Naval Undersea Museum, Keyport, WA for educational purposes.

### ***Procurement Information***

The system was developed cooperatively between NSW, National Park Service, and ManTech Corporation. ManTech Corporation can support further development and implementation of this system.

### ***Future Development***

No future development is planned; however the system can be modified for specific usage. If prospective users have specific requirements, the system can be modified to allow for:

- Additional hydrophone channels.
- Expanded or modified frequency ranges.
- Use with other sensor types.
- Other sample schemes, Other data products.

Information needed from research scientists and resource managers to guide future development:

1. Objective of acoustic monitoring.
2. Area of acoustic monitoring coverage.
3. Is face of phone level measurement required (dB re 1 microPa)?
4. Is source level measurement required (dB re 1 microPa at 1 meter)?
5. Source types of interest (vessels, seismic activity, marine mammals, etc.).
6. Is localization of sources of interest?
7. Are the sources cooperative?
8. Approximate acoustic source levels expected.
9. Frequency range of interest.
10. Types of data products required.
11. How will data analysis and source identification be accomplished?
12. Oceanographic characteristics of area of interest.
13. Are fixed acoustic sensors acceptable?
14. Is there a facility in the area where the data stream can make land fall?
15. Duration of system deployment.
16. Desired temporal extent of monitoring (i.e., continuous coverage, sample coverage, etc.)
17. Approximate project budget.

**Kremeyer, Kevin**  
**PM & AM Research**  
**Washington D.C., U.S.A.**

A primary focus of our research involves the interaction of lasers and fluids:

One technology we would like to extend to passive acoustic measurement is inelastic scattering of electromagnetic radiation from acoustic waves in the ocean. A common form of this phenomenon is Brillouin scattering, in which laser light interacts with acoustic vibrations in transparent solids, effectively doppler shifting the radiation. This shift can be measured to determine the acoustic spectrum in the solid. Since the coupling coefficient is greatest for identical wave numbers ( $k$  in the denominator), the desired probe wavelengths are determined by the acoustic range to be measured. A second consideration in determining the probe wavelength is the penetration or “skin depth” into the ocean. The technique is passive in that electromagnetic waves are directed into the medium, and the scattered signal is also read from outside the medium.

A second technique we have been using to measure acoustic vibrations is direct measurement of the displacement of a membrane. We have performed this by selecting a membrane to vibrate over the range of interest (e.g., properly tuning a speaker or microphone membrane) and then measuring this displacement optically, instead of electrically. This measurement has been performed using both an optical interferometer and a fiber-optic probe. Both techniques are conducive to passive measurement of membrane vibrations over wide frequency ranges. They are passive once again in the sense that the optical signal propagates into and back out of the medium, carrying with it the desired acoustic information. In other words, the laser or light goes in “clean” and comes out with the desired data. We have developed deconvolution algorithms for a number of different measurement scenarios.

This approach has not yet been developed for passive acoustic measurements and, as such, does not have an associated component cost. The basic components required are a source (laser/optical to RF/microwave), receiver (same as emitted frequencies), and a computer to analyze the signal.

Information needed from technology users to guide exploratory development includes the general pressure levels of the signals, frequency range, and noise characteristics. Additional information includes at what depths the signals can or must be measured and any special ocean environments/conditions of interest.

**Lauth, Robert and S. McEntire**  
**NOAA Alaska Fisheries Science Center**  
**Alaska, U.S.A.**

***Portable Underwater Video Camera and Winch System for Studying Fish Behavior***

A custom portable underwater video camera and winch system was designed and built for locating Atka mackerel (*Pleurogrammus monopterygius*) spawning and nesting sites and learning about their spawning and nesting behavior in the Aleutian archipelago, Alaska (Lauth 2007). Linking passive acoustics to behavioral work is a research need that was identified by Rountree et al. (2001). Adding an autonomous acoustic recorder to the portable camera system would make it a

relatively inexpensive and practical tool for simultaneous recording of *in situ* audio and behavioral video data. Its original design was for day or night use in rocky areas with current down to water depths of 200m. The system takes one person to operate and is small enough to use on a 16' inflatable and rugged enough to be used on a commercial fishing vessel in moderate weather. Because it is portable, it can be used on vessels of opportunity. It was built with off-the-shelf components that cost approximately \$15K. A color CCD camera (0.05 lux) is used with available light, and a low-light black-and-white CCD camera (0.0003 lux) is used in low light conditions or at night. In total darkness, a red light emitting diode (LED) array is used in conjunction with the low-light CCD camera to illuminate the area viewed by the camera. The camera has real-time video feed with GPS overlay to a topside mini-DV recorder and head mounted video display. Time-referenced temperature and depth is recorded with a Seabird SBE 39 attached to the camera frame. Real-time monitoring is necessary to avoid obstacles while the video camera drifts over the irregular bottom. The camera frame height-off-bottom is at about 1m and is adjusted with the variable speed electric winch.

### ***Winch & Cable Specifications***

Welded aluminum frame, drum, and boom; Leeson ¾ HP 24VDC 29 Amp motor; Leeson 40:1 variable speed controller; MyTe Winch gearbox; Mercotac Model 430 4-conductor Slip Ring; 70Amp battery isolator; 50 Amp surface mount circuit breaker; Furnas WR44 reversing motor drum switch; WagnerSmith 10" diameter conductor stringing block modified with idler arms; 305 m (1000') 24AWG, 4-conductor, double armor, 4.72 mm (0.186") diameter cable, working load 1,300 lbf, breaking strength 3,300 lbf, PMI Industries Cable-Grip strain relief; and, Impulse connectors.

### ***Drop Camera Specifications***

35 lb aluminum frame including 3 lead weights and all the jewelry; Sony SuperHAD exView CCD Imager cameras with C/CS mount - B&W 420 lines resolution & 0.0003 lux and color 480 lines resolution & 0.05 lux; machined stainless steel camera housings; ½" CS-mount 3.8mm aspherical lenses (F 0.8 – 360); DeepSea Power & Light Rite Lite with diffused red LED array (other lights can also be used); 13.2 NiMH battery pack 3300mah inside PVC housing; SeaBird SBE39 temperature and depth datalogger

### ***Deck Unit Specifications***

SONY GV-D300 mini-DV recorder; Intuitive Circuits GeoStamp; NITEK VB37F passive transmitter and TR560 active receiver; Garmin low-profile GPS antenna; Eyeneo Eyetop Centra head mounted display; and, Hoffman water-tight enclosure.

### ***References***

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**Lammers, Marc and Kevin Wong and Rusty Brainard  
Hawaii Institute of Marine Biology and NOAA Coral Reef Ecosystem Division  
Hawaii, U.S.A.**

### ***Ecological Acoustic Recorder (EAR)***

The EAR is a digital, low power system that records ambient sounds up to 30 kHz on a programmable schedule, but can also respond to transient acoustic events that meet specific criteria, such as vessels passing nearby. There are two types of EAR: a shallow-water (0 - 36 m) version that is diver-deployed and a deep-water version that is rated to a depth of 500 m. The deep EAR is recovered by activating an acoustic release that allows the unit to float back to the surface. The shallow-water EAR can be deployed for a year or longer, depending on the number of batteries included and the recording schedule. The deep EAR can be deployed for up to 6 months at a time.

The system is based on a Persistor CF2 microprocessor and a 16-bit analog to digital converter that records the ambient sound field and stores the recordings on an onboard 120 Gb disk. Recording sessions are initiated in one of three ways: on a software-regulated schedule, on a start trigger tuned to vessel-generated acoustic energy, and/or on a trigger tuned to sounds produced by cetaceans.

To date, the EAR has been used to record long-term acoustic patterns on coral reefs, monitor vessel traffic in marine reserves, track the occurrence of cetaceans in an area, and establish the acoustic signaling behavior of bottom fish.

### ***Working with the EAR***

There are three ways to work with the EAR: as a Data Solicitor, as an Instrument Leaser, or as a Project Collaborator. The cost will depend on the use agreement, the number of units required, the type of unit(s) (shallow vs. deep), and the duration of use. The three use categories are summarized as follows:

**Data Solicitor (DS)** – Individuals or agencies interested only in a data product with no need or desire to interface directly with the EAR hardware or raw data. EAR units are deployed at specified sites for a specified duration and a CRED-authored report is produced following the deployment period summarizing the results. Cost range \$8,000 - \$15,000. DS is also responsible for any deployment costs beyond shipping from/to Hawaii.

**Instrument Leaser (IL)** – Individuals or agencies desiring to work with the EAR hardware and capable of data analysis without further assistance from HIMB/CRED. EAR units are leased by the user on a monthly or yearly basis and are returned upon completion of the contract. Cost range: \$4,000 - \$8,500 + lease of topside unit for acoustic releases for deep EARs (\$300/deployment/recovery). IL is responsible for shipping costs from/to Hawaii and deployment costs.

**Project Collaborator (PC)** – Individuals or agencies interested in entering into a collaborative agreement with HIMB/CRED. The PC pays for hardware costs and HIMB/CRED absorb the labor

costs of building the EAR unit(s). The data are shared and presentations/publications are authored jointly. EAR units are returned to HIMB/CRED at the end of the collaboration. Cost range: \$2,500 - \$7,500. PC is responsible for shipping costs from/to Hawaii and deployment costs.

**Olson, Joe**  
**Cetacean Research Technology**  
**Washinton, U.S.A.**

*Cetacean Research Technology (CRT) manufactures hydrophones for use in a variety of systems.*

***RUDAR (Remote Underwater Digital Acoustic Recorder)***

- The RUDAR is a calibrated, programmable, underwater acoustic recording device that can record audio files and/or compute and log SPL files and 1/3-octave spectrum files.
- Specs: Uses C54- or C304-series hydrophones and a customized ST400 mobile data recorder (see below) housed in a 7"OD pressure canister. Sample-rate and quantization are selectable up to 96kHz/24-bit, Frequency response of 8Hz to 40kHz, Sensitivity of -165dB (at 0dB gain, adjustable from -20 to +40dB), Depth rating of 1500m to 3500m, Data storage from 80GB to 0.5TB, Record for days to months depending on recording scheme and batteries.
- Required gear: Computer with Internet browser useful, but not required, for programming. SpectraPRO or SpectraLAB software recommended for signal analysis, but any signal/sound analysis software, such as MatLab, can also be used.
- Examples of use: Two very crude concept prototypes of the RUDAR were built for a NOAA coral reef monitoring project during 2002. These concept prototypes used C54 hydrophones and off-the-shelf compact flash recorders, with only 2GB memory, housed in 12" PVC pipes. Little feedback on the results of the initial deployments has been received, but the units leaked and we believe were not used again. The current RUDAR design has not yet been built.
- Cost: \$12,500 for 1500m, single-channel, standard battery-pack, 80GB model.
- Purchasing info: The RUDAR will only be built once an order is received and may take up to 6 months to build and fully test. Partial payment will be required in advance with installments being made during the manufacturing process. Final payment is due prior to shipping.

***ST400 Mobile Data Recorder***

- The ST400 is manufactured by CRT's strategic partner, Sound Technology, Inc. It is a fully programmable, remote access (via embedded web server), general purpose data recorder.
- Specs: Frequency response of <1Hz to 40kHz; Sample rate and quantization scaleable up to 96kHz/24-bit; Input voltage range from <1mV to 70Vrms (+/-100Vpeak); Records audio files in WAV format; Logs SPL(air), SPL(water), 1/3 Octave Spectrum,  $L_{EQ}$ , SEL,  $L_{min}$ ,  $L_{max}$  in Text or XML format; User-defined sample schemes and file management; Powered by 9V to 35VDC; hot-swappable low-power USB2 hard drives; Optional GPS time server and reference clock.

- Required gear: Computer with Internet browser required for remote programming. SpectraPRO or SpectraLAB software recommended for signal analysis, but any signal/sound analysis software, such as MatLab, can also be used.
- Examples of use: Besides remote monitoring of environmental soundscapes, the ST400 has also been utilized to collect acoustic signatures for a wide variety of acquisition and monitoring applications related to planes, trains, automobiles, submarine detection, natural resource exploration, surveillance, satcom, security, telcom, seismic, munitions, enterprise networks; related deployments include vehicular, airborne, shipboard, space, AUV, UAV, and other demanding applications.
- Cost: \$7,500 to \$15,000
- Purchasing info: Payment in advance with delivery in one to four weeks depending on options.

***RASP (Registratore Acustico Subacqueo Programmabile, a.k.a. Programmable Underwater Acoustic Recorder)***

- The RASP is manufactured by CRT's European distributor, Nauta. It is a light-weight, easily deployable, programmable, underwater acoustic recording device.
- Specs: Uses Sensor Technology SQ26-06 hydrophone, a modified M-Audio MicroTrack 24/96 compact flash recorder, and a custom timer circuit housed in a 9cm OD pressure canister; Sample rate and quantization are selectable up to 96kHz/24-bit; Frequency response of 20Hz to 40kHz; User programmable sampling scheme; Data storage up to 4GB; Record for hours to weeks depending on sample scheme and battery capacity.
- Required gear: PC for setting the timer. Battery charger.
- Examples of Use: The RASP was designed for the European "Del.Ta." project and is being used by Nauta to record underwater sound data as part of the project's purpose of monitoring daily bottlenose dolphin activities and their movements associated with interactions with fishing gear and pingers in order to find effective solutions for conservation. The first RASP to be used in the USA was just delivered to the NOAA National Ocean Service Center for Coastal Environmental Health and Biomolecular Research where it will be used to monitor dolphins.
- Cost: \$3,500 (without programmable timer) to \$8,500 (with all options)
- Purchasing info: The RASP will be built to order and takes up to 4 months to build and fully test. 50% payment is due in advance with the balance due prior to shipment.

***Hydrophones on Internet-linked buoys***

- Some of our customers have used the C54XR and C54XRS hydrophones on near-shore buoys with a solar powered radio link to a shore base station. The audio signal is then streamed to the Internet for monitoring and analysis.
- Specs: C54XR and C54XRS hydrophones. Radio bandwidth 5kHz to 20kHz.
- Cost: unknown except for price of hydrophone, which is \$659 to \$759.
- Purchasing info: These are custom applications and may not be for sale.

***Information Request for End-Users***

What maximum bandwidth would you like from a recorder or real-time monitoring device?

What maximum deployment time would you like from a remote recorder?

With limited battery and data storage capacities, would you trade an easily deployable package for continuous data recording?

Recording can currently be triggered by a signal-level threshold. Would you like advanced automatic signal detection? If so, would you prefer bandpass-filtered signal-level triggering, match-filter triggering, or something else? Since automatic signal detection is not 100% reliable, would you rather use this method to reduce storage requirements, or would you prefer to mine the data in post processing?

**Sprague, Mark W. and Joseph J. Luzkovich**  
**East Carolina University**

*Device: FABULS – Fish Acoustic Buoy and Underwater Logging System (prototype)*

- Originally funded by NOAA/CICEET
- Digital audio recording device and datalogger 0.01 – 22 kHz sensitivity range, with HTI 96-min hydrophone
- Submersible to 200 feet
- Records to Compact Flash media (2 GB in prototype up to 16 GB available) for archival purposes, date and time stamped
- Battery life ~ 1 month (depends on sampling frequency used)
- Solar panel rechargeable (in development)
- Software developed to record and store WAV files recorded at 22050 Hz, 10 s each 15 min (programmable to other durations and sampling frequencies) – 2 GB CF card will hold approximately 40-50 days of sound recordings at this sampling rate.
- Runs LINUX Operating System on an ARCOM VIPER PC104 computer (Intel PXA255 processor 400 MHz)
- Interfaces with serial devices (e.g., computer for download and program set up, Nortek Aquadopp current meter, GPS, YSI model 6600 EDS, etc.)
- Serial and Ethernet ports – can be controlled by spread spectrum radio, cellular or satellite phone
- Reduced data set uploadable to a base computer via Kermit and radio or phone modem (in development)
- Recorded sounds: Biological sounds (toadfish, weakfish, spotted seatrout, red drum, silver perch, striped cusk eels, snapping shrimps, bottlenose dolphin, etc. Also, it will record vessels and weather events: wind, waves, rain).
- Cost: \$1500 each for components; not marketed as of now.

**Upton, Zachary**  
**BBN Technologies**

*Technology Developer Summary*

BBN has a long history of providing remote sensing systems to the U.S. Navy and other organizations for hydroacoustic monitoring. Our staff includes a team of experts in data analysis and algorithm development for hydroacoustics and a team of software engineers dedicated to real-time



processing of acoustic signals. We have developed a software architecture called the Signal Processing Engine/Display Programming Environment (SPE/DPE)<sup>TM</sup> that enables rapid prototyping of real-time data acquisition, signal and information processing, and display software for a host of off-the-shelf hardware. We have implemented, deployed, and delivered these systems for active and passive anti-submarine warfare in Hawaii for the Center of Excellence for Research in the Ocean Sciences (CEROS), for COMDESRON 15 in the Pacific Fleet, and for the U.S. Navy Submarine Force Pacific (SUBPAC). For example, we continue to support SUBPAC with our Portable Sonobuoy Range, which enables SUBPAC to conduct training exercises in remote locations by providing asset monitoring and tracking in real-time during the exercise. This system is currently deployed on U.S. Navy P-3 aircraft and continuously monitors a field of sonobuoys in real-time. We are working with CEROS to reduce dependency on the P-3 by developing a COTS airborne receiver and processor for multiple sonobuoys. The package is being designed to also relay information to remote monitoring centers or ships with an emphasis on the use of expendable lighter-than-air platforms.

The strength of the SPE/DPE architecture lies in its adaptability, allowing BBN to quickly produce real-time monitoring systems for a variety of applications. Our tools have been applied to a variety of sensors, from bottom-moored hydrophones, to digital and analog sonobuoys, to radar sensors. BBN works with its customers to select the best sensors and processing hardware to suit the specific application's requirements for frequency response, persistence, processing complexity, ruggedness, and a host of other parameters.

BBN has deployed many systems to monitor marine mammals and the effects of noise on those animals. We have conducted multi-year efforts to monitor the effects of oil exploration noise on whale feeding and migration, rock fish, and crab development in the Arctic and Pacific Oceans. BBN has built monitoring systems to monitor the underground tunnel excavation and blasts with both seismic and radio-relayed autonomous hydrophone spar buoys. We have also monitored cruise ship noise in Alaska in order to determine the effects of this noise on marine mammals. We continue to explore the application of many of our algorithms, software, and tools to marine mammal monitoring.

Finally, BBN has been at the forefront of remote monitoring of sensor signals. We have deployed land-based systems that communicate processed data results over satellite links to remote analysis stations. As noted above, we are developing technologies to relay sonobuoy data to standoff locations using UAVs or lighter-than-air platforms. These could have direct application to the remote hydroacoustic monitoring of marine mammals.

### ***Information Required to Guide Future Development***

To guide tool development in this area, we require information on the signals of interest (bandwidth, duration, amplitude), the use/deployment of the system (sensor lifetime, processing system robustness and location, processing system power requirements, etc. ), and the end-user requirements. For example, if the user is going to look at acoustic signals and do analysis, the system design and display requirements are very different from the requirements of a system that is intended to detect, classify, and track marine mammals with minimal user interaction. Finally, we would need to collaborate with Resource Managers to balance these requirements with available funding.





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ACT Headquarters  
c/o University of Maryland Center of Environmental Science  
Chesapeake Biological Laboratory  
Post Office Box 38  
Solomons, Maryland 20688-0038  
Email: [info@act-us.info](mailto:info@act-us.info)