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Workshop Proceedings

BIOLOGICAL PLATFORMS FOR SENSOR TECHNOLOGIES AND THEIR USES AS INDICATORS OF THE MARINE ENVIRONMENT

Seward, Alaska
September 19-21, 2007

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

An ACT Workshop Report

A Workshop of Developers, Deliverers, and Users of Technologies for

Monitoring Coastal Environments:

Biological Platforms for Sensor Technologies and their Uses as Indicators of the Marine Environment

Sponsored by the Alliance for Coastal Technologies (ACT) and NOAA's Center for Coastal Ocean Research in the National Ocean Service.

Hosted by the University of Alaska Fairbanks and the Alaska SeaLife Center, ACT Partner Organizations.

ACT is committed to developing an active partnership of technology developers, deliverers, and users within regional, state, and federal environmental management communities to establish a testbed for demonstrating, evaluating, and verifying innovative technologies in monitoring sensors, platforms, and software for use in coastal habitats.

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Executive Summary

The Alliance for Coastal Technologies (ACT) Workshop entitled, "Biological Platforms as Sensor Technologies and their Use as Indicators for the Marine Environment" was held in Seward, Alaska, September 19 – 21, 2007. The workshop was co-hosted by the University of Alaska Fairbanks (UAF) and the Alaska SeaLife Center (ASLC). The workshop was attended by 25 participants representing a wide range of research scientists, managers, and manufacturers who develop and deploy sensory equipment using aquatic vertebrates as the mode of transport.

Eight recommendations were made by participants at the conclusion of the workshop and are presented here without prioritization:

1. Encourage research toward development of energy scavenging devices of suitable sizes for use in remote sensing packages attached to marine animals.
2. Encourage funding sources for development of new sensor technologies and animal-borne tags.
3. Develop animal-borne environmental sensor platforms that offer more combined systems and improved data recovery methodologies, and expand the geographic scope of complementary fixed sensor arrays.
4. Engage the oceanographic community by:
    a. Offering a mini workshop at an AGU ocean sciences conference for people interested in developing an ocean carbon program that utilizes animal-borne sensor technology.
    b. Outreach to chemical oceanographers.
5. Min v2d6.sheepserver.net e and merge technologies from other disciplines that may be applied to marine sensors (e.g. biomedical field).
6. Encourage the NOAA Permitting Office to:
    a. Make a more predictable, reliable, and consistent permitting system for using animal platforms.
    b. Establish an evaluation process.
    c. Adhere to established standards.
7. Promote the expanded use of calibrated hydrophones as part of existing animal platforms.
8. Encourage the Integrated Ocean Observing System (IOOS) to promote animal tracking as effective samplers of the marine environment, and use of animals as ocean sensor technology platforms.

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 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 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 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.

Biological Platforms for Sensor Technologies and their Uses as Indicators of the Marine Environment Workshop Goals

Planning for the ACT Workshop on Biological Platforms was undertaken with the following objectives in mind:

- Summarizing current sensor technologies and applications which utilize marine vertebrates to collect environmental data;
- Encouraging the advancement of the technology through fruitful discussion between sensor developers and the scientists who deploy these sensors; and
- Determining ways to gain a broader acceptance of the environmental data obtained from biological platforms by the oceanographic community.

In order to achieve these objectives the following goals were presented during the opening session:

- Build consensus on the steps needed to promote the development and deployment of sensor packages capable of recording high-resolution environmental data when attached to marine vertebrates as platforms of opportunity.
- Identify how the resources of the Alliance for Coastal Technologies can be applied to this goal.

Organization of the Workshop

The workshop was sponsored by ACT and hosted by the Alaska SeaLife Center and the University of Alaska Fairbanks. Both comprise the ACT Alaska Regional Partner Institution. The workshop was organized by Drs. Shannon Atkinson and Russ Andrews (UAF), Phil Mundy (NOAA) and Casey Moore (WET labs), with Jessica Ryan serving as the workshop facilitator (Alaska SeaLife Center).

On the first evening, workshop participants convened for a reception and dinner in the Alaska SeaLife Center's Underwater Viewing area. Dr. Mario Tamburri gave a presentation on the mission of the ACT program, followed by a keynote address by Dr. Michael Fedak, from the University of St. Andrews, UK.

The workshop commenced the following day with an introduction by Dr. Andrews, and discussion of the workshop format by Dr. Atkinson. Attendees to the workshop were divided into two groups for the two plenary sessions. Questions were provided in order to facilitate discussion. The groups in the first session were divided into sensor users and sensor manufactures, and the groups in the second session were divided alphabetically, with A-F in one group, and G-Z in the second group.

A spokesman from each group gave a presentation to the workshop attendees after each plenary session.

The final wrap-up session was attended by all workshop participants. The session opened with a summary of common issues raised during the prior plenary sessions. A prioritizing discussion by the participants yielded a list of eight goals to be implemented or facilitated by ACT.

Biological Platforms: State of the Science

Sensor technology using marine vertebrates as "vehicles of opportunity" allows for environmental data collection under conditions that would be difficult or cost-prohibitive with standard data collection procedures, for example, under sea ice. Certain constraints limit the usefulness of these animal-borne sensors and were the topic of much discussion during the first session of the workshop. The following is a summation of issues discussed during the workshop on the state of the science of sensor technology that can be used on biological platforms:

- Data collected: current sensor technologies using biological platforms produce data for temperature, pressure (depth), acceleration, conductivity, and light level (which is used to measure geolocation, turbidity, chlorophyll, and oxygen).
- Package size: increased animal size does not necessarily correlate to larger instrumentation packages. Whales, for example, often brush off applied devices, so smaller or imbedded tags are often longer lasting than larger tags. Moreover, larger attachments increase drag and can affect mobility and survival. Currently, whales are tagged with an egg-sized tag that records temperature and depth. The smallest tags, about the size of a dime, are implanted in fish to record temperature and depth and can last up to 20 years, according to Dr. Andrews.
- Power source: some sensor packages are too large and have too high of an energy demand to be used broadly. Advancements in technology for energy scavenging or re-powering the device after deployment would alleviate many of these constraints. At least two companies have Small Business Innovative Research Grants to further development of energy scavenging equipment. Some very small scavenging devices work vibrationally, similar to self-winding watches, but so far nothing along these lines has been successfully developed for marine mammals.
- Location: in the North Sea, English Channel, and elsewhere, sensor development has taken advantage of local properties such as tides, and has been used to aid in establishing animal (flatfish) movements based on characteristic variations in tidal height.
- Data storage and retrieval: memory storage is not limiting, as even small tags can hold adequate data storage for most applications. Retrieval of data is obtained through satellite telemetry or by recovering archival tags that wash up on beaches or are retrieved once the animal dies. Generally, marine mammals provide opportunities for satellite communication because the tags are applied externally. However, fish tags are applied internally, which precludes satellite transmission.

- Data Results: environmental sensors deployed on aquatic animals can produce a wide range of graphic descriptions of the animal's movement through the water, and offer important insights. One example is the documenting of animal migrations over broard areas of the South Atlantic. As a wider range of data is collected from more advanced sensor packages, there will be a greater need for even more sophisticated methods of synthesizing the collected data.

Motivation for Utilizing Biological Platforms

There is great potential for broader application of biological platforms for sensor technology. Tagged animals can sample extensive areas and unique geospacial aspects of the ocean, which are otherwise inaccessible, ice covered, or too expensive for conventional sampling. Moreover, the data from biological platforms complements data collected from traditional oceanographic platforms (e.g., vessels, moorings, buoys). For example, animals typically go to rich divergence zones or onto continental shelves, whereas traditional approaches randomly or systematically sample, and therefore spend a high proportion of the sampling effort in low productivity waters. Consequently, instrumented vertebrates can be used as bioindicators, collecting key biological data from regions that may otherwise be difficult to sample, or can be used to help identify areas of particular importance (e.g., critical habitat for ESA listed species).

Data from marine animals have the dual benefit of providing oceanographic data while yielding biological information about tagged animals. The link between the two is important, and the ethics of using animals can be justified by the biological data obtained. The data is critical for understanding the environment in which they live, relative to animal behavior, climate change, environmental changes, and the fate of the animals.

From a biological standpoint, tagging could eventually help define preferred and critical habitats by linking the state of the animal with the state of the environment in a single sensor. Sensors may be useful to better understand animal behavior, geolocation, energy flux due to feeding, life history parameters, and preference of habitats.

Ultimately, data from biological platforms are critical for understanding the environment animals utilize, so we can recognize how changes in the environment will affect these animals.

Challenges in Using Biological Platforms to Collect Environmental Data

Marine biologists face several challenges when using animals as biological platforms. These challenges include a lack of acceptance by many scientists in the oceanographic community, technological challenges such as the need for smaller tags and longer tag life, attachment issues, cost of development and deployment, and public opposition by some groups to equipping marine animals with sensor equipment.

Acceptance from the oceanographic community is one of the key challenges biologists face in using biological platforms to collect environmental data. The arguments given by oceanographers are (1) the lack of random sampling because instrument bearing vertebrates do not follow a standardized sampling protocol, and (2) data that do not meet industry standards for accuracy. Conveying the value of using animals to collect environmental data is difficult because it is truly a cross-disciplinary science. Biologists in this arena are creating a new scientific discipline, and the questions they ask are not specific to biology or oceanography, but belong to a multi-disciplinary field combining the tools and research opportunities of both fields. To satisfy oceanographers, data would need to match current industry standards for accuracy. However, it may expedite technology development for biologists to establish standards that meet the biologists' needs for frequency of sampling or degree of accuracy, rather than being held to the standards of accuracy required by oceanographers.

Technological challenges persist, particularly the need for building smaller tags while gaining longer equipment life spans. Temperature and water pressure are routinely collected, while salinity measurements have proven more difficult to obtain. Sensors that sample for a broader range of environmental parameters are still in the developmental stage. Additionally, there are problems with adding more functionality to sensors because sending data via satellite has intrinsic limits, owning to bandwidth restrictions. In non air-breathing species, such as fish, data recovery is still a limiting issue, as the tags must be retrieved in order to download data.

Attachment techniques and limitations are another challenge. Biologists can't always use adhesives to attach external tags to animals. Therefore, in some situations and for some species, biologists use implantable devices, which is an inherently more difficult and invasive method. Tags may also affect animal behavior. The saying, "Any data is better than no data" is not always true, especially if the tag attached changes the very behavior that it was meant to measure.

The current costs of tags can be prohibitive. CTD's (tags which measure conductivity, temperature, and depth) are about $10,000 per unit, plus deployment. For small applications with marine mammals (where the cost of capture and tagging each individual is very substantial), this is reasonable. However, at these unit costs the technology is not feasible for use on thousands of animals. Successful development of large-scale scientific studies might see a dramatic reduction in the costs of the technology, as is widely observed in other areas of electronics.

A final challenge biologists face is public opposition to the perceived misuse of marine animals. The public and other scientists do not always believe that tagging is the best way to gather data. There is a need to educate the public up front, rather than doing damage control after the fact. Through appropriate educational opportunities the public should be informed about the sensor application, the permitting process, and why the data are necessary in order to win their support. The opportunity exists to further this outreach to include people who develop environmental policy, implement management practices, and write environmental impact statements.

Ways to Improve the Technology

Smaller, cheaper, easier, and longer life: the prevailing mantra of the workshop was for sensor tags that are smaller, and therefore less intrusive, that can be attached quickly and easily; have a longer battery life in order to extend the data collection period; and are cost effective.

More functionality: technological advancements should focus on getting more accurate and precise data on the location of animals. For example, a tag that will accurately record or identify the deepest dive of the day provides information of considerable use to the research community. There is a need for CTD tags that give GPS data for location. Additionally, two-way communication between the tag and the observer would allow the observer to increase intensive sampling or reduce sampling intervals as needed. This would allow for better power budgeting. Current tags do not know what data has been received, so data is retransmitted, creating redundancy. Two-way communication could result in less data transmission and longer battery life.

Data recovery: there is a significant need for more real-time data that allows for ongoing marine vertebrate observations and information on current oceanic conditions. For example, real-time data for turtles could aid in mitigation techniques to reduce fishing by-catch. Fast GSM (Global System for Mobile communications) acquisition would allow for quick data retrieval, but some animals never come into GSM range. Another possibility would be to transmit data from one animal to another. For example, a tagged non-surfacing animal could convey data to a tagged air breathing animal which would in turn transmit that data via satellite; or hydrophones on Steller sea lions could capture orca sounds. Information download zones for animals near rookeries or other areas of population concentration could allow for near-time transmission. These suggestions may be facilitated by developing Radio Frequency Identification at Ultra High Frequency (UHF RFID).

Software*:* User-friendly software, both on-board and post-processing, is needed. It would be helpful if software designers could provide information on what the software can or can not do, build in flexibility, and provide a set of tools on how to use them. Alternatively, software could be standardized within the field.

Benefits from other technologies: In order to advance the field of sensor equipment, manufacturers should pursue collaborations with geochemistry and microtechnology industries, as well as technological applications in oceanography. (e.g. AUV's (Autonomous Underwater Vehicles) and gliders). RAFOS (SOund Fixing and Range spelled backwards) are underwater GPS navigation systems recently used to sense floats that track the Atlantic Gulf Stream and have an accuracy range of 1000 – 2000 meters. They give positional data, but not physical conditions, and consist of a small receiver with a custom chip with very low power requirements. The information resides in the tag, and if the tag surfaces, it can be picked up by buoy triangulations. They are currently being developed to be smaller, which will broaden their application options. In the world of Micro Electrical Measuring Systems (MEMS), oxygen sensors can print on a chip. Design is the most expensive aspect and may run $50,000. However, once designed, production would be cost-effective.

Ideal Sensor Technology Tool

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A better understanding of sensor equipment requirements for biologists and oceanographers is needed. While an ideal sensor would meet the needs of both user groups, packaging sensors for a spectrum of capabilities, and building in flexibility, rather than attempting to develop a one-size-fits-all, may be the best means of meeting user needs. Sensor designers should distinguish between nearshore and offshore use, meet the desired parameters, and determine levels of accuracy. The following table breaks down desired environmental and physiological parameters for biological research into two-year and five-year development goals.

Table 1: Desired Advancements in Sensor Technology.

Develop over next 2 years:			
Sensor	**Biology and/or Oceanography**	**Offshore**	**Coastal**
3D Location	B O	5 – 100 km	m – 1 km
Pressure	B O		
Temperature	B O		
Conductivity	B O	0.01	0.01
Develop over the next 5 years with smaller size and longer deployment time:(a rating of '1' is highest need)			
		Biology	**Oceanography**
DO		1	1
pCO2		3	1
pH (water)		2	1
Chlorophyll/Fluorescence		2	2
Passive and Active Acoustics		1	3
Additional parameters for future development: (a rating of '1' is highest need)			
		Biology	**Oceanography**
Video			
Heading/Acceleration		2	3
Light		3	3
Optical scatter/Turbidity		3	3
Fitness			
Speed		1	
Mortality		1	
Acceleration		2	
Doppler blood flow		1	
Growth rate		?	
Feeding (pH)		1	
Fat		1	
Heart rate		2	
Sonar/Echo sounder		2	

Additional Desirable Tag Capabilities: sensors that combine CTD with GPS capabilities would be in great demand. Other technology advancements would include creating small sensor "docking bays" so that multiple tags can be plugged in or removed, as well as communication with each other; wireless tags; tags that are low profile and leave a small footprint; and tags that provide desired levels of data accuracy. Size could be reduced by using buoyant tags that would release themselves from the animal, storing the data until they are retrieved.

Desirable Energy Resources: sensory technology is currently constrained by inadequate energy resources. This requirement may be met through the development of rechargeable batteries; solar cells (for animals that sun themselves); by developing smart technology, which allows the operator to turn the battery on and off so a one-year battery can last longer (ideally five years or more); or captured energy.

Desirable Data Transmission Capabilities: there is a need for sensors that: combine faster transmission speed and fewer message length constraints with real-time tracking; allow for two-way communication; and provide an assessment of animal and environmental parameters simultaneously.

The Future of Sensor Technology Using Biological Platforms

Future technology should lead to sensors that provide an array of environmental parameters and yield information about the animals upon which they are attached. These environmental data would include under ice observations, data which can be used to mitigate human-marine resource conflicts, and systematic monitoring of anthropogenic noise, amongst other emerging topics. Sensors would be small and inexpensive enough to be used on a large number of animals, including both predator and prey species. From a biological perspective, sensor data should contribute greatly to understanding the life history of the animals being studied, as well as the habitat conditions that support these animals, making each animal a bioindicator of its environment.

Concurrently, the use of marine animals should gain support from the oceanographic community, with these animals becoming viewed as platforms of opportunity. Tag-bearing species should play an important role in monitoring ecosystem health, as the data collected would be of value to both biologists and oceanographers. Biological platform research should complement research conducted with AUVs and ROVs by putting tags on animals that can mesh with technologies that can not be attached to animals. Ideally, oceanographers would contribute funding towards ongoing research in order to include their desired sensors in biological platform data collection.

Information for Manufactures

Manufacturers need input from technology users to facilitate sensor technology development that will meet the needs of biologists and oceanographers. This input should include package size restrictions and a discussion of the trade-offs between size and power needs. Scientists should specify the degree of accuracy required to provide quality data, sampling frequency, depth robustness, and simplicity of use vs. smart technology that will allow for communication between the sensor and the user. Finally, manufacturers should be appraised of the desired data recovery method and any interface issues, permit requirements, quantity needs, and the amount of funds available to develop the product.

Workshop Recommendations

Sensor technology utilizing biological platforms began some 25 years ago, and as such, is a relatively new means of collecting environmental data. In the ensuing years, thanks to remarkable strides in computer technology and data storage, tags are substantially smaller, last longer, and yield far more data than in the past. Despite these gains, technological advancements are not keeping stride with the biological community's need to obtain and understand information that is necessary for state-of-the art management practices, nor are they currently able to provide the information needed to run multidisciplinary models that can predict how species will respond to climate change. In order to facilitate this process, attendees at this ACT workshop put forth the following workshop recommendations:

1. Encourage research toward development of energy scavenging devices of suitable sizes for use in remote sensing packages attached to marine animals.

2. Encourage funding sources for development of new sensor technologies and animal-borne tags.

3. Develop animal-borne environmental sensor platforms that offer more combined systems and improved data recovery methodologies, and expand the geographic scope of complementary fixed sensor arrays.

4. Engage the oceanographic community by:

   a. Offering a mini workshop at an AGU ocean sciences conference for people interested in developing an ocean carbon program that utilizes animal-borne sensor technology.

   b. Outreach to chemical oceanographers.

5. Mine and merge technologies from other disciplines that may be applied to marine sensors (e.g. biomedical field).

6. Encourage the NOAA Permitting Office to:

   a. Make a more predictable, reliable, and consistent permitting system for using animal platforms.

   b. Establish an evaluation process for permitting.

   c. Adhere to established standards.

7. Promote the expanded use of calibrated hydrophones as part of existing animal platforms.

8. Encourage the Integrated Ocean Observing System (IOOS) to promote animal tracking as effective samplers of the marine environment, and use of animals as ocean sensor technology platforms.

Acknowledgements

ACT, ASLC and UAF would like to thank everyone who attended this workshop for their enthusiastic participation. A special thanks goes to the workshop planning committee: Drs. Russ Andrews and Shannon Atkinson with UAF/ASLC; Casey Moore with Wet Labs; Dr. Phil Mundy of Auke Bay Laboratories, National Marine Fisheries Service; and ACT Executive Director Dr. Mario Tamburri. In addition, we would like to thank Dr. Michael Fedak for his outstanding keynote speech. The successful organization of this workshop is credited to Jessica Ryan, Angie Steeves, and Jilian Chapman of the ASLC. The workshop was fully supported by the Alliance for Coastal Technologies, a NOAA-sponsored program.

Appendix A. List of Attendees

Russ Andrews, Ph.D.
University of Alaska Fairbanks - School of Fisheries and Ocean Sciences/
Alaska SeaLife Center
PO Box 1329
Seward, AK 99664
russ_andrews@alaskasealife.org

Peter Armato, Ph.D.
Ocean Alaska Science and Learning Center
Kenai Fjords National Park
PO Box 1727
Seward, AK 99664
Peter_Armato@nps.gov

Shannon Atkinson, Ph.D.
University of Alaska, Fairbanks - School of Fisheries and Ocean Sciences/Seward Marine Center
PO Box 730
Seward, AK 99664
Shannon_Atkinson@alaskasealife.org

Torie Baker
Alaska Sea Grant Marine Advisory Program
PO Box 830
Cordova, AK 99574
907-424-3673
torie@sfos.uaf.edu

Mary Ann Bishop, Ph.D.
PO Box 705
Cordova, AK 99574
907-424-5800
mbishop@pwssc.gen.ak.us

Robert Byrne, Ph.D.
140 7th Avenue South
College of Marine Science
University of South Florida
St. Petersburg, FL 33701
727-553-1508
byrne@marine.usf.edu

Michael Cameron, Ph.D
Alaska Fisheries Science Center - Polar Ecosystems Program
National Marine Mammal Laboratory (NOAA)
7600 Sand Point Way NE
Seattle, WA 98115
206-526-6396
Michael.Cameron@noaa.gov

Dan Costa, Ph.D.
Institute of Marine Biology, Center for Ocean Heath,
University of California
100 Shaffer Road,
Santa Cruz, CA 95060
813-459-2786
costa@biology.ucsc.edu

Doug DeMaster, Ph.D.
AK Fish and Science Center (NOAA)
7600 Sand Point Way N.E. F/AKC3
Seattle, WA 98115-6349
206-526-4000
douglas.demaster@noaa.gov

Michael Fedak, Ph.D.
Sea Mammal Research Unit
Gatty Marine Research Institute
University of St. Andrews
St. Andrews Fife
UK KY168LB
01334 463218
maf3@st-andrews.ac.uk

Howard Ferren
Alaska SeaLife Center
PO Box 1329
Seward, AK 99664
907-224-6396
howard_ferren@alaskasealife.org

Bill Hagey
Pisces Design
6621 Avenida Mirola
La Jolla, CA 92037
858-459-8554
piscesbill@yahoo.com

Appendix A. List of Attendees (continued)

Roger Hill, Ph.D.
Wildlife Computers
8345 154th Avenue NE
Redmond, WA 98052
425-881-3048
Roger@wildlifecomputers.com

Kim Holland, Ph.D.
Hawaii Institute of Marine Biology
University of Hawaii
PO Box 1346
Kane'ohe, HI, 96744
808-236-7416
kholland@hawaii.edu

Anne Hoover-Miller
Alaska SeaLife Center
PO Box 1329
Seward, AK 99664
907-224-6396
Anne_Hoover-Miller@alaskasealife.org

Tim Linley, Ph.D.
MariCal, Inc.
400 Commercial St.
Portland, ME 04101
tlinley@marical.biz

Brian Marquardt, Ph.D.
Senior Research Engineer
Applied Physics Laboratory
University of Washington
Seattle, WA 98195
206-543-6054
brian@cpac.washington.edu

Molly McCammon
Alaska Ocean Observing System
1007 West Third Ave. Suite 100
Anchorage, AK 99501
907-644-6703
mccammon@aoos.ogr

James Miller, Sc.D.
University of Rhode Island
Department of Ocean Engineering
Narragansett, RI 02882
401-874-6540
miller@uri.edu

Casey Moore
WET Labs
PO Box 518
Philomath, OR 97370
541-929-5650
casey@wetlabs.com

Phil Mundy, Ph.D.
National Marine Fisheries Service (NOAA)
11305 Glacier Hwy
Juneau, AK 99801
907-789-6001
phil.mundy@noaa.gov

Alexei Pinchuk, Ph.D.
University of Alaska, Fairbanks
Seward Marine Center
PO Box 730
Seward, AK 99664
907-224-4313
ftaip1@uaf.edu

Mario Tamburri, Ph.D.
One Williams Street
Solomons, MD 20688
410-32-7440
tamburri@cbl.umces.edu

David Welch, Ph.D.
Kintama Research Corporation
10-1850 Northfield Rd.
Nanaimo, BC V9S 3B3
205-714-0045
david.welch@kintamaresearch.org

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Copies may be obtained from:
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