Alliance for Coastal Technologies Indexing No. ACT-03-05

Workshop Proceedings

Biofouling Prevention Technologies for Coastal Sensors/Sensor Platforms

Solomons, Maryland
November 19-21, 2003

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

UMCES Technical Report Series: TS-426-04-CBL / Ref. No. [UMCES]CBL 04-016

An ACT 2003 Workshop Report

A Workshop of Developers, Deliverers, and Users of Technologies for Monitoring Coastal Environments:

Biofouling Prevention Technologies for Coastal Sensors/Sensor Platforms

Solomons, Maryland
November 19-21, 2003

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

Hosted by ACT Partner organization Chesapeake Biological Laboratory of the University of Maryland Center for Environmental Science in Solomons, Maryland.

ACT is committed to develop 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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ACT WORKSHOP: BIOFOULING PREVENTION TECHNOLOGIES FOR COASTAL SENSORS/SENSOR PLATFORMS

EXECUTIVE SUMMARY

Biofouling control is considered a key impediment for sensor technologies used in aquatic environmental monitoring, especially in the coastal zone. Besides the obvious affects on sensors and platforms, biofouling affects both the maintenance costs and resulting data quality of the deployed sensors.

The biofouling of ships, other large submerged structures and now instrumentation are typically controlled through the use of toxic paints incorporating metal biocides (e.g. cuprous oxide) and organometals (e.g., tributal tin, TBT). Further, alternative mechanical systems, such as sensor head wipers, have been developed and implemented as antifouling on sensors.

This ACT workshop, Biofouling Prevention Technologies for Coastal Sensors/Sensor Platforms, was organized to address this ubiquitous problem of biofouling for sensor technologies. The workshop sought to define existing control techniques and discuss them in context of specific sensor types. In this context the attendees worked to identify the requirements for biofouling controls, associated environmental issues, and discuss both current and experimental methods of biofouling control.

Through a series of breakout and plenary sessions, the workshop attendees identified biofouling problems associated with a range of acoustic, optical, and electrode sensor technologies and the application of a variety of biofouling methodologies. currently used. The workshop participants also explored a wide range of immediate and long term candidate technologies.

Based on their discussions, the attendees developed major operational and technical conclusions:

Operatonal Conclusions:

- monitoring systems are moving toward longer instrument deployments that exacerbate biofouling effects on operations
- battery needs and data storage issues in observing systems have been in great part overcome, thus making biofouling the major impediment to longer deployments
- maintenance costs due to biofouling are high - about one half of most operational budgets

Technical Conclusions:

- a range of sensor type-specific biofouling solutions is needed
- the coating technologies developed and optimized for the shipping industry need to optimized or modified though R&D for sensors
- much of the developing technologies are being developed by the sensor instrument companies themselves
- one of the most promising new areas of biofouling control is localized sterilization systems such as UV and chlorine generation
- the effects of biofouling on data QA/QC has not been tested or quantified to an adequate degree

Based on their discussions, the attendees developed a series of specific recommendations to facilitate the development of appropriate methodologies for handling biofouling of sensors. The recommendations were focused on: urging R&D to quantify the effects of fouling on sensor performance, quantifying the cost of biofouling on monitoring budgets, and encouraging a variety of forums for the exchange of informaiton on sensor biofouling facts and developing technologies.

ALLIANCE FOR COASTAL TECHNOLOGIES

There is widespread agreement that an Integrated Ocean Observing System is required to meet a wide range of the Nation's marine product and information service needs. There also is consensus that the successful implementation of the IOOS will require parallel efforts in instrument development and validation and improvements to technology so that promising new technology will be available to make the transition from research/development to operational status when needed. Thus, the Alliance for Coastal Technologies (ACT) was established as a NOAA-funded partnership of research institutions, state and regional resource managers, and private sector companies interested in developing and applying sensor and sensor platform technologies for monitoring and studying coastal systems. ACT has been designed to serve as:

- An unbiased, third-party testbed for evaluating new and developing coastal sensor and sensor platform technologies,
- A comprehensive data and information clearinghouse on coastal technologies, and
- A forum for capacity building through a series of annual workshops and seminars on specific technologies or topics.

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 goals are to both help build consensus on the steps needed to develop and adopt useful tools while also facilitating the critical communications between the various groups of technology developers, manufacturers, and users.

ACT Headquarters is located at the UMCES Chesapeake Biological Laboratory and is staffed by a Director, Chief Scientist, and several support personnel. There are currently seven ACT Partner Institutions around the country with sensor technology expertise, and 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. Finally, a larger body of Alliance Members has been created to provide advice to ACT and will be kept abreast of ACT 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.actonline.ws.

BIOFOULING BACKGROUND INFORMATION

The biofouling of ships, marine platforms, submerged structures and now oceanographic instrumentation represents one of our most plaguing maintenance and operational problems when working on and under both marine and freshwater environments. The military, commercial shipping industries have always been and will continue to be the most effected marine industry segment impacted by biofouling. As an example, the costs to the shipping industry in prevention, maintenance, efficiency and fuel consumption is in the tens of billions of dollars. The majority of biofouling control coatings and methods have been developed specifically for the shipping industry. This is not surprising when one considers both the maturity of the shipping industry as well as the surface areas of the worlds shipping fleet as compared to all other submerged structures, buoys and instrumentation combined.

Historically, biofouling control has been achieved by exploiting the toxicity of metals, organometals and other biocides to marine invertebrates and incorporating them in antifouling coatings. The most common biocides used in modern antifouling coatings are cuprous oxide, and tributal organotin (TBT). The paint matrixes in which the biocides are contained and ultimately released are highly engineered systems with the more sophisticated coating matrixes working through a means of ablative or self polishing actions that continuously expose fresh biocide to the surface of the coating.

The most effective biocide as well as the most controversial is TBT. Evidence of adverse effects caused to the marine environment from the use of antifouling coatings incorporating TBT and to lesser extent cuprous oxide biocides on boats, ships and marine structures has resulted in current and pending national and international regulations controlling the use of these substances. In anticipation of severe restrictions concerning the use of the traditional antifouling biocides, the U.S. Navy and maritime industry have directed a significant research effort towards developing non-toxic and less toxic antifouling technology, and non metal biocides. The result of this research and development and present state of the art in antifouling technology for boats and ships are non TBT paints consisting of: self polishing cuprous-oxide, cuprous oxide/non metal biocide combinations and non-toxic easy release coatings.

One of the more promising technologies to have evolved from this research are the non-toxic easy release coatings noted, which are typically low surface energy materials such as silicone rubbers. These materials have only seen limited application because they do require regular cleaning for most ship applications and are very susceptible to abrasion resistance. The advanced cuprous oxide and co biocide paints have been more successful and are in many cases less toxic to the environment by virtue of the paint matrix's controlled release rates of the biocides.

Where antifouling control methods are incorporated into undersea instrumentation applications, they are in many cases coatings which have originally been developed for shipping and applied in their original or modified form to instrumentation. In addition to the biofouling control methods described that have been adopted from the shipping industry, instrumentation manufacturers have developed specialized mechanical cleaning systems that have seen widespread implementation. These systems typically consist of mechanical wipers that clean small sensor heads at regularly timed intervals.

BIOFOULING PROBLEM DEFINITION FOR INSTRUMENTATION AND PLATFORMS

Biofouling is for a large percentage of instrumentation deployments, the single biggest factor affecting the operation, maintenance and data quality of in water monitoring sensors. This is especially true for instrumentation deployments in the coastal zones. Furthermore, the problem has been exacerbated by the requirements for and advances in instrumentation technology which results in longer and longer in-situ instrument deployments. The major impediments to long term instrumentation deployments used to be data storage and battery life. Over the years instrumentation has become more power efficient, better battery systems have evolved and data capacities greatly increased. As such, the major impediment to longer instrumentation deployments for many operational scenarios is biofouling accumulation.

Biofouling inhibits sensor operations and diminishes performance by: inferring with membrane and electrode sensors, interfering with water flow through orifices and hoses, adding weight to the instrumentation, adding hydrodynamic drag to the instrumentation and inhibiting the mechanical movement of some sensor types. Platform performance is diminished through increased weight, increased hydrodynamic drag, and interference with mounted sensors. While the cost of biofouling to instrumentation and mounting platforms has not been quantified, it is not unusual for to have the majority of the long term cost of instrumentation deployment dominated by biofouling control and maintenance.

The user communities primary goal is to achieve longer instrument deployment. Although a variety of mechanical cleaning methods, coating applications of various material types and chemical control methods are practiced, there are very few clear guidelines for the application of specific biofouling control techniques to specific sensor types, platform types and environmental/operating conditions.

WORKSHOP GOALS

There where three primary goals of the workshop. The first goal was to define the various existing and experimental biofouling control techniques. The second goal was to match the identified techniques with specific sensor types, platform types and operational/environmental conditions where it would be most effective. The final objective of the workshop was to separate black art and myth from effective technology as it applies to biofouling control. To address these goals, the workshop participants were asked to:

- Identify the requirements for biofouling control on instrumentation, floating platforms and submerged structures.
- Identify environmental issues related to specific biofouling control methods.
- Identify biofouling control methods currently used for instrumentation, floating platforms and submerged platforms.
- Match currently available biofouling control methods to specifically identified biofouling control requirements.
- Evaluate experimental and non-traditional biofouling control methods and their applications.

- Identify the most promising technologies for biofouling control that require further research and development.

WORKSHOP STRUCTURE

The workshop was hosted by the Chesapeake Biological Laboratory (UMCES) in Solomons Island MD on November 19-21. Hank Lobe (RD Instruments/Marine Safety Systems) and Richard Zimmerman (Old Dominion University) acted as organizers and facilitators.

Thirty four participants were invited to the workshop. Attendees are shown in Appendix A. The invitees were selected to included equal representation from the research community (coating, instrumentation and biofouling researchers), management community (users of sensor data) and industry (coating and instrumentation developers and manufacturers).

Introductory addresses were given at the beginning of the workshop on Wednesday evening, November 19th and Thursday morning November 20th. The first presentation by Dr. Steve Lawrence of the Naval Research Laboratory focused on biofouling solutions developed by commercial coatings companies and tested for use by the U.S. Navy. The second presentation was delivered by Warren Krug of the NOAA, NOS, CO-OPS program and cited specific examples of biofouling's impact on: submerged sensors, the operations required to and support instrumentation deployments and the resulting data products.

The workshop format consisted of two breakout sections. The breakout sections were held in the morning and afternoon of Thursday Nov 20th. The morning break session consisted of three groups of like disciplines while in the afternoon the breakout session consisted of three groups of mixed discipline participants. The breakout session topics were as follows:

MORNING SESSION

Subject 1: Identify the requirements for biofouling control on instrumentation, floating platforms and submerged structures.

Subject 2: Identify performance limitations for the biofouling control examples cited.

AFTERNOON SESSION

Subject 3: Identify traditional biofouling solutions that are suitable for implementation.

Subject 4: Identify and evaluate experimental and non-traditional biofouling control methods and their applications. Identify of the most promising areas of biofouling control that require further research and development.

A summary session consisting of all participants was held directly after the morning and afternoon break out sessions. Finally, a plenary session reviewing all of the workshop findings was conducted

WORKSHOP FINDINGS

PROBLEM IDENTIFICATION AND LIMITATIONS OF SENSORS

The workshop attendee's categorized the sensor types into three categories; Acoustic, Optical and Electrodes. Within these categories the present performance limitations and desired performance requirements were identified for the types of sensors noted.

There is no magic bullet for biofouling control. The variety of instrument types deployment scenarios, and environmental conditions preclude a single biofouling solution.

OPTICAL SENSORS

Optical Sensors are used for the turbidity, fluorometer, plankton and chlorophyll measurements.

- Three month to one year deployments are required
- Zero tolerance for fouling
- Mechanical in-situ wiper systems are effective but can cause damage due to abrasion
- The mechanical wipers can become inoperable due to biofouling
- Clear AF coatings do not exist
- Data degradation usually occurs immediately with no biofouling protection. Present protection methods can enable optic sensors to work for up to three months.
- Instrument calibration as biofouling degradation occurs is an important concern that has not been addressed.
- Traditional AF coatings can be used to protect the housing elements of systems.
- Hazardous materials issues are a concern for manufacturers servicing instruments returned to them with unknown AF coatings applied to the instrument housings.

ACOUSTIC SENSORS

Acoustic Sensor's most common applications are for Acoustic Doppler Current Profilers (ADCPs), and Acoustic Modems.

- One year deployments without biofouling damage to the ADCP transducer heads is required for accessible areas. Three year deployments are required for remote area locations.
- One of the most significant impacts biofouling has on acoustic devices is damage to the transducer faces from hard biofouling settlement such as barnacles.
- The use of copper based paints on the transducer had can result in undesirable galvanic reactions with the transducer outer ring of aluminum.
- The most widely used acoustic devices are ADCPs
- Of all sensor types, acoustic sensors have the highest tolerance for biofouling. Biofouling is in all but extreme cases transparent to the acoustic devices such as ADCPs.
- When severe biofouling does occur, it affects the range of acoustic instruments first. The precision of the data obtained typically suffers minor or no degradation.
- Acoustic devices can suffer from weight and drag issues from biofouling accumulation.
- Biofouling can impede the operation of mechanical automated release mechanisms used to recover submerged acoustic instrumentation.
- It is possible to suffer from air entrapment in biofouling growth which does disturb the acoustic signal.
- Hazardous materials issues are a concern for manufacturers servicing instruments returned to them with unknown AF coatings applied to the instrument housings.

ELECTRODE AND SENSORS

Electrode sensors sometimes incorporate membranes and are used to measure conductivity, dissolved oxygen, temperature and PH.

- Three month to one year deployments are required
- Of all sensor types sensors incorporating electrodes and membranes are the most susceptible to inoperability and data degradation due to biofouling.
- For worst case scenarios, electronic and membrane sensors can require daily maintenance.

- Cannot coat electrodes with conductive metal based biocides as it will disturb the instrument calibration.

- Electrode devices can suffer from weight and drag issues from biofouling accumulation.

- Wiper mechanisms can sometimes be used.

- The mechanical wipers can become inoperable due to biofouling.

- Membranes cannot be coated.

- For systems requiring circulation and pumping, clogging and filtration is an issue.

- Hazardous materials issues are a concern for manufacturers servicing instruments returned to them with unknown AF coatings applied to the instrument housings.

PLATFORMS

Platforms are defined as bottom mooring systems, buoys, and mounting frames.

- Deployment time required is one to two years

- Platforms used to mount submerged sensors are typically protected using traditional copper based antifouling paints.

- It is possible for fouling on platforms to become so severe that it will interfere with the water flow past some instruments or in some cases prevent mechanical actuators from releasing instruments.

- Traditional antifouling paints work well on moorings if properly maintained.

PROBLEM SOLUTIONS

The workshop attendees identified presently implemented solutions, and near term and long term solutions for the three classes of instrumentation being evaluated. An overview of the technologies identified and their applications are provided below.

PRESENTLY IMPLEMENTED BIOFOULING CONTROL METHODS

The following biofouling control methods are those which presently used for instrumentation applications.

Copper Based Paints - Widely used control method, 3 month to 1 year effectiveness, may be handling and application hazards, susceptible to slime buildup. Ablative and self polishing paints are recommended.

Applications - instrument housings, platforms

TBT Based Paints - Seldom used control method, due to regulatory issues, excellent performance with 1 to 3 year deployments common, high toxicity, handling and application hazards, environmental hazards. Ablative and self polishing paints are recommended. TBT based coatings can reduce or prevent biofouling on optical, acoustic, and electrode sensor areas by applying the coating to surface areas close to but not in contact with the sensing area itself. For acoustic devices, TBT coatings can be applied directly to the transducer faces.

Applications - instrument housings, platforms, optical faces, acoustic transducer faces, electrodes

Co Biocide Copper Paints - Moderately used control method, newest copper based paint, technologies use non metal and copper biocides, designed to prevent slime buildup in addition to soft and hard fouling control, 3 month to 1 year deployments. Ablative and self polishing paints are recommended.

Applications - instrument housings, platforms

Peroxide Based Paints - Moderately used control method, low toxicity, 3 month to 1 year deployments.

Applications - instrument housings, platforms

Silicone Greases - Moderately used control method, acts as a non toxic barrier and ablative surface, short term effectiveness at 1 to 3 months

Applications - instrument housings, acoustic transducer faces

Red Pepper in Silicon Grease and Paint - Moderately used control method, not scientifically proven, short term effectiveness at 1 to 3 months

Applications - instrument housings, acoustic transducer faces

Non Stick Silicon Rubber - Seldom used control method, requires cleaning at regular intervals, susceptible to abrasion damage, non-toxic, long term effectiveness can be up to 5 years or greater

Applications - instrument housings, platforms

Mechanical Wipers - Widely used control method, limited cleaning areas, used for optical and electrode systems, 3 month to 6 month effectiveness

Applications - optical faces, electrodes

Shutters - Moderately used control method, works by isolating sensor to light and biofouling growth conditions, limited surface areas, used for optical and electrode systems, 3 month to 6 month effectiveness

Applications - optical faces, electrodes

Peel Away Plastic Wraps - Moderately used control method, may not increase deployment times but does reduce cleaning during maintenance, typically a thin conforming plastic wrap, practical for short term deployments

Applications - optical faces if optically clear, instrument housings, acoustic transducer faces

CANDIDATE TECHNOLOGIES FOR INTERMEDIATE AND LONG TERM IMPLEMENTATION

The following biofouling control methods are those which have a high likelihood of being providing benefit for instrumentation applications.

Advanced Shutter Systems - The development of shutter systems for a larger variety of sensors, enclosed areas may be filled with a non seawater biofouling growth inhibiting liquid.

Applications - optical faces, electrodes, acoustic transducer faces

Advanced Peel Away Coverings - Peel away coverings designed for specific instrumentation requirements. The coverings may have clear optical or acoustic qualities or contain biocides if required.

Applications - optical faces, electrodes, acoustic transducer faces

Harder Materials for Acoustic Transducers - The development and implementation of harder polyurethanses or substitute materials that will resist the damage presently incurred when hard fouling organisms settle on such surfaces.

Applications - acoustic transducer faces

Ultrasonics - The testing, development and implementation of intermittent operated ultrasonic systems. Ultrasonic is to date an unproven technology for biofouling control.

Applications - optical faces, electrodes, acoustic transducer faces

UV Sterilization - The development testing and implementation of an intermittent UV sterilization process. The technology would be applied to transducer and sensor probes.

Applications - optical faces, electrodes, acoustic transducer faces

Localized Chlorine Generation - Research and development has been conducted for the development of local chlorine generation from seawater. The technique has application for sensor head areas.

Applications - optical faces, electrodes, acoustic transducer faces

Rotating Turrets - Develop a system turrets where biofouling sensor heads would be replaced by a fresh sensor head.

Applications - electrodes

Smooth Surfaces - There are advantages to be realized by producing very smooth surfaced sensor faces. Biofouling settlement and the ability to mechanically clean surfaces are enhanced when the surface roughness of such faces is an absolute minimum. The technique is especially applicable to optical sensors.

Applications - optical faces, electrodes, acoustic transducer faces

Increased Use of Foul Release Coatings - Low surface energy coatings such as silicone rubber have proven effectiveness for delaying biofouling settlement and decreasing cleaning efforts once settlement has occurred. These coatings are susceptible to abrasion damage.

Applications - instrument housings, platforms

Red Pepper Formulations - There are significant numbers of users that believe that red pepper grease and paint formulations are effective biofouling treatments. There is no substantiated test data to support these claims.

Applications - instrument housings, platforms, electrodes, acoustic transducer faces

Self-polishing Surfaces - The development and implementation of sensor head surfaces that are either made of ablative materials or are coated with ablative coatings which render the surface clean and biofouling free at intermittent intervals.

Applications - optical faces, electrodes, acoustic transducer faces

Optically Clear Biocides - The development of clear biocides would allow these coatings to be used on optical sensors.

Applications - optical sensor faces

Advanced Co-Biocide Copper Based Paints - The newest generation of co-biocide copper paints are predicted to be more effective for biofouling control than the present market products.

Applications - instrument housings, platforms

TBT Collars - The strategic placement of TBT collars and impregnated surfaces is an effective means of providing biofouling control to biofouling susceptible sensor areas.

Applications - optical faces, electrodes, acoustic transducer faces

Self Calibrating Instrumentation to Account for Biofouling - The implementation of self calibrating instrumentation will help alleviate data degradation from biofouling.

Applications - optical faces, electrodes, acoustic transducer faces

WORKSHOP MAJOR CONCLUSIONS

The major conclusions from all of the information presented and reviewed at the workshop are presented below. The conclusions are divided into the categories of operational and technical considerations.

OPERATIONAL CONCLUSIONS

1. The major impediments to long term instrumentation deployments used to be data storage and battery life. Over the years instrumentation has become more power efficient, better battery systems have evolved and data capacities greatly increased. As such, the major impediment to longer instrumentation deployments is in fact biofouling.

2. The user communities primary goal with is to achieve longer instrumentation deployments.

3. The cost of biofouling is high in terms of both the quality of sensor data obtained and the labor hours devoted to maintain equipment that is impacted by biofouling. For the worst case scenarios up to one half of operational budgets are due to biofouling.

4. There are many operational scenarios where the merits of accuracy and precision should be weighted. Where accuracy can be maintained but precision may be degraded due to biofouling, considerations should be made to lessen the requirements for precision, thus allowing longer deployment times.

5. Real time monitoring is very valuable for determining instrument degradation due to biofouling. As telemetry and automatic flagging systems gain widespread use this will be a valuable in the mitigation of biofouling impact.

TECHNICAL CONCLUSIONS

1. The effects of biofouling on instrumentation data has in most cases not been tested or quantified. This should be a major consideration for the testing and qualification of instrumentation.

2. There is no magic bullet for biofouling control. The variety of instrumentation types, deployment scenarios and environmental conditions preclude a singe biofouling solution.

3. The coatings used by the instrumentation community for biofouling control were developed for the shipping industry. These coatings have been optimized for ship and boats, not instrumentation. The instrumentation community does not provide a large enough marketplace for paint manufacturers to develop specialized coatings for this application.

4. The development of coatings is very slow. Except for the case of non-toxic foul release coatings, the regulatory requirements for the sale of coatings incorporating new and innovative biocide types takes many years and is very costly.

5. The application, user exposure and servicing of instruments incorporating the use of toxic biocides has to be considered whenever and where ever these materials are used.

6. Many of the most effective biofouling control solutions have been developed by the instrumentation manufacturers themselves. A good example of this are the wiper systems available from instrument manufacturers for optical systems. Manufactures are motivated to provide value added features for which they can charge a premium. Manufacturers are also wise to consider the fact that lower maintenance requirements for instrumentation may free up dollar resources for additional instrument purchases.

7. One of the most promising areas of new biofouling control methods is the further development of localized sterilization treatments such as UV and chlorine generation. The present state of the art development for these technologies is within the biomedical industry.

WORKSHOP RECOMMENDATIONS AND ACTION ITEMS

The following recommendations and action items were determined:

1. Quantify the effects of fouling on sensor performance by duration and environment. Manufacturers and third party independent testing agencies should provide users with data which quantifies the effects of biofouling on a particular instrument. If possible user

guidelines for calibration due to biofouling should be provided. As a start to this process, ACT needs to consider biofouling impact on all instrument tests.

2. Quantify the cost of biofouling, instrument failure, data loss and maintenance. The quantification and total dollar value assignment of costs due to biofouling will help to encourage the funding and development of new biofouling control methods as well as the implementation of operational procedures which mitigate biofouling's impacts.

3. Inform Ocean.US and other governing entities involved with Ocean Observatories and long term sensing about the data quality and dollar impact of biofouling. These entities should actively be supporting efforts to address biofouling issues.

4. Create a user-forum and for biofouling problems, issues and solutions as it relates to in instrumentation use. An ACT maintained web site is thought to be a good method of implementing such a user forum.

5. Follow-up workshops should be organized to help implement and monitor the findings of this workshop. Future workshop attendees should include participation by the commercial paint companies and the biomedical industry.

6. Encourage regional seminar/training sessions on instrument use and biofouling mitigation techniques by ACT partners. ACT partners should be encouraged to share their knowledge as related to biofouling in there particular environments, missions and instrumentation types.

7. Determine the legal requirements for using TBT. TBT is for some instrumentation applications an effective easily implemented near term and cost effective method for biofouling control. The short and long term availability and legal requirements for using TBT coatings is not understood by the instrumentation user community.

8. A test program should be instituted to determine if red pepper is an effective biocide. If red pepper is an effective biofouling prevention agent, its use should be expanded for those applications that require low toxicity short term biofouling protection.

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ACT Biofouling Workshop Participants
Solomons, Maryland
November 19-21, 2003

University of Maryland Technical Report Series No. TS-426-04-CBL

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