ADVANCING ENVIRONMENTAL INNOVATIONS:

20 YEARS OF THE

ALLIANCE FOR COASTAL TECHNOLOGIES

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Advancing Environmental Innovations: 20 years of the Alliance for Coastal Technologies

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This 20-year retrospective of ACT is dedicated to the memories of Ken Tenore, Marlin Atkinson, and Kenneth Coale, who were each instrumental in the development and success of this unique and important program.

EXECUTIVE SUMMARY

This report is a 20-years review of the Alliance for Coastal Technologies (ACT), 2001-2021. ACT was established by the National Oceanic and Atmospheric Administration (NOAA) in 2001, creating new paradigms to bring innovative, revolutionary marine and freshwater environmental sensing technologies to the market and into operations. It arose at a time when the United States began moving toward the development and implementation of a sustained, national Integrated Ocean Observing System (IOOS). ACT organized its products and services as the U.S. Commission on Ocean Policy, in preparing "An Ocean Blueprint for the 21st Century," was examining the transition of marine technologies from the research and development stages to sustained applications.

ACT functions as a partnership of federal and state agencies, academia, and the private sector. ACT priorities are 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 environmental observing community with information required for the deployment of reliable and cost-effective environmental monitoring networks. ACT provides three fundamental public services to meet its goals:

- a third-party testbed for quantitatively evaluating the performance of new and existing coastal technologies in the laboratory and under diverse environmental conditions,
- a forum for capacity and consensus building through technology specific workshops and training opportunities that reviewed the current state of instrumentation, built consensus on future directions, and enhanced communications between users and developers, and
- an information clearinghouse through a searchable online database of environmental technologies and community discussion boards.

ACT's core set of values are integrity, teamwork, independence, impartiality, transparency, and excellence. ACT-generated verification data have helped to:

- build vendor credibility by providing the marketplace with the assurance that technology performance claims are valid and supported by high-quality, independent test data;
- enable technology users and investors to make informed decisions when identifying and selecting suitable technologies and to better manage technology and investment risks; and
- provide policy makers, regulators and other stakeholders with clear information on the performance achievable by environmental technologies.

From the time it began stakeholders' technology needs assessments and program design in 2000, ACT has made significant strides to making its vision of "becoming an international resource for facilitating the transition of environmental technologies to routine use in coastal environments" a reality. Among its accomplishments, ACT has:

- organized a networked, "co-laboratory," consisting of a coordinating Headquarters unit and regionally distributed and geographically diverse partner research institutions, with appropriate expertise, facilities and mechanisms for extensive stakeholder participation;

- established an internationally recognized, rigorous and quality assured, third-party testing infrastructure and process for evaluating existing, new and developing sensor and sensor platform technologies;
- conducted 421 verifications and demonstrations of marine and freshwater sensors and sensor systems in multiple diverse environments and applications;
    - 11 instrument classes (dissolved oxygen, nutrients, and chlorophyll a fluorometry were done twice) in controlled laboratory conditions and in hand-held, moored, depth profiling, and surface mapping applications in field sites including Kaneohe Bay, HI, Resurrection Bay, AK, Monterey Bay, CA, Chesapeake Bay, MD, the Gulf of Maine, the Gulf of Mexico, and the Great Lakes;
    - Most of the 34 companies that participated in the verifications are small- to medium-sized enterprises (SMEs) from around the world (based in 6 different countries), in addition to the US; 14 companies participated multiple times (1 company participated in 10 verifications);
- created an innovative technical workshop format in which participants from all relevant sectors, i.e., research and development (R&D), manufacturing, and "operational" environmental management, convened to describe the state of technologies and to create roadmaps for future development. A total of 49 technology workshops were conducted, involving over 1,500 participants from around the world; and
- developed an unprecedented online searchable database of environmental instrumentation as a resource for coastal managers, scientists and observing systems.

ACT has achieved these outcomes with:
- highly qualified teams of field-experienced scientific leadership and testing and quality assurance (QA) experts;
- mature, robust, and flexible testing frameworks;
- proven testing methodologies;
- custom solutions; and
- superior quality management systems.

ACT does not rank nor certify technologies (e.g., Consumer Reports, Underwriters Laboratories). Certification is applicable when there is a known standard or specification that is either nationally or internationally recognized. Rather, ACT testing provides evidence that verifies performance claims of new, innovative, near-commercial and commercially available technologies and presents a clear assessment of the technology's environmental fitness of purpose for which it was designed. Results from ACT activities have been used by various regulatory (e.g., EPA) and operational monitoring agencies (e.g., NOAA, USGS) for the approval and use of various instruments.

ACT continues to evolve its capabilities and services that were developed and refined over the past two decades to meet shifting user requirements, providing experience and leadership in transitioning to sustainable technological solutions that are robust, flexible, and resilient to meet global environmental challenges. ACT is a unique innovation-enabling organization, and the importance of reliable/dependable instruments for moored and autonomous observations translates into a great need for independent *in situ* testing of existing and emerging devices. However, there currently are no comparable federally-funded environmental technology verification programs in the United States.

Support for ACT during its first 20 years has been primarily from NOAA (Coastal Services Center [CSC] and the Integrated Ocean Observing System [IOOS] Office), with technology specific support also received from the U.S. Environmental Protection Agency (USEPA), the U.S. Maritime Administration (MARAD), the U.S. Coast Guard (USCG), Naval Research Laboratory (NRL), the U.S. Geologic Survey (USGS), and the U.S. Department of Agriculture (USDA). Participating partners, collaborators, and technology developers/manufacturers have also provided in-kind support in various ACT activities.

ACRONYMS

ACT	Alliance for Coastal Technologies
AGU	American Geophysical Union
ANSI	American National Standard Institute
ASQC	American Society for Quality Control
ASLC	Alaska SeaLife Center
ASLO	Association for the Sciences of Limnology & Oceanography Aquatic Sciences
BGSU	Bowling Green State University
BOEMRE	Bureau of Ocean Energy Management, Regulation, and Enforcement
CAGR	Compound annual growth rate
CBL	Chesapeake Biological Laboratory
CBOD	Carbonaceous biochemical oxygen demand
CDOM	Colored dissolved organic matter
CICEET	Cooperative Institute for Coastal and Estuarine Technology
CO_2	Carbon dioxide
CO-OPS	Center for Operational Oceanographic Products and Services
COTS	Coastal Observation Technology Systems
CSC	Coastal Services Center
DO	Dissolved oxygen
eDNA	Environmental DNA
EOV	Essential ocean variables
ETV	Environmental Technology Verification
EU	European Union
FQY	Chlorophyll-a fluorescence quantum yield (FQY)
GLERL	Great Lakes Environmental Research Laboratory
GOOS	Global Ocean Observing System
GoMOOS	Gulf of Maine Ocean Observing System
GSI	Great Ships Initiative
HAB	Harmful algal bloom
HABHRCA	Harmful Algal Bloom and Hypoxia Research and Control Act
HABSOS	Harmful Algal Blooms Observing System
HIMB	Hawaii Institute of Marine Biology
HIF	USGS Hydrologic Instrumentation Facility
IEC	International Electrotechnical Commission
IOC	Intergovernmental Oceanographic Commission
IODE	International Oceanographic Data and Information Exchange
IOOS	Integrated Ocean Observing System
ISO	International Standards Organization
IV&V	Independent verification and validation
MARAD	Maritime Administration
MERC	Maritime Environmental Research Center
MLML	Moss Landing Marine Laboratories
MQO	Measurement quality objective

MTU	Michigan Technological University
NDBC	National Data Buoy Center
NEMI	National Environmental Methods Index
NEON	National Ecological Observing Network
NERACOOS	Northeastern Regional Association of Coastal and Ocean Observing Systems
NFM	National Field Manual for the Collection of Water-Quality Data
NGO	Non-governmental organization
NIST	National Institute of Standards and Technology
NOAA	National Oceanic and Atmospheric Administration
NOPP	National Oceanographic Partnership Program
NOC	National Oceanographic Centre
NPDES	National Pollutant Discharge Elimination System
NRL	Naval Research Laboratory
NSF	National Science Foundation
NWQMC	National Water Quality Monitoring Council
OOI	Ocean Observatories Initiative
OBPS-R	Ocean Best Practices Repository
OSTP	Office of Science and Technology
PAM	Multiple turnover Pulse Amplitude Modulated
pCO_2	Partial pressure of carbon dioxide
qPCR	Quantitative real-time polymerase chain reaction
R&D	Research and development
QAPP	Quality assurance project plan
QARTOD	Quality Assurance of Real-Time Ocean Data
QA/QC	Quality assurance and quality control
QM	Quality manager
QMS	Quality management system
RA	Regional association
R&D	Research and development
SBIR	Small Business Innovation Research program
SCCWRP	Southern California Coastal Water Research Project
SERC	Smithsonian Environmental Research Center
SkIO	Skidaway Institute of Oceanography
SME	Small- to medium-sized enterprise
SOEST	University of Hawaii School of Ocean and Earth Science and Technology
SOP	Standard operating procedure
TA	Total alkalinity
TMDL	Total maximum daily load
TRO	Total residual oxygen
TSA	Technical systems audit
UAF	University of Alaska Fairbanks
ULL	University of Louisiana Lafayette
UMCES	University of Maryland Center for Environmental Science
UM/CIGLR	University of Michigan and the Cooperative Institute for Great Lakes Research

UNESCO	United Nations Educational, Scientific and Cultural Organization
USACE	United States Army Corps of Engineers
USCG	United States Coast Guard
USDA	United States Department of Agriculture
USEPA	United States Environmental Protection Agency
USF	University of South Florida
USGS	United States Geological Survey

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1. INTRODUCTION

Aquatic environments around the world are confronted with unprecedented natural and anthropogenic stressors resulting in significant impacts to various economic, ecological, societal, and cultural resources (e.g., IOC-UNESCO, 2022). As a result of the continued burning of fossil fuel resulting in ocean acidification and over fertilization of farmlands resulting in nutrient pollution, eutrophication and hypoxic “dead zones”, to over fishing and oil spills, accurate, reliable and affordable technologies are needed to identify environmental concerns, track changes, mitigate impacts and successfully protect and manage aquatic resources.

New and emerging markets are continuing to develop for environmental innovations to address these critical needs, benefiting manufacturers of monitoring instruments. Technologies are converging that will provide unprecedented capability for monitoring and exploring freshwater ecosystems, the coastal zone and deeper ocean. Rapid progress continues in the development of traditional tools of aquatic research, such as tethered and autonomous vehicles and acoustic, atmospheric and optical sensing devices. Cutting-edge biological and chemical sensors have become available to provide information in all environmental domains. At the same time, advances in information technology, electronics and communications offer the possibility of deploying large networks of devices to gather and transmit data that can be examined in real time or stored for later analysis or used in simulation and modeling scenarios. These trends and realities demonstrate a need to facilitating the transition of promising technologies into operations and to providing technology verification services to instrumentation developers as more end-users and authorities begin to require third-party performance-based information for purchase and deployment decisions.

The various end-user segments of the environmental technologies market include government agencies, public utilities, academic and research institutions, and maritime industrial sectors (e.g., shipping, fisheries/aquaculture, offshore energy). The users of environmental technology performance verification services and information include technology developers, technology manufacturers and vendors, customers, and technology enablers, e.g., government and regulatory bodies, that facilitate technology adoption through standards, guidelines, policies, funding and investment.

Small and medium-sized enterprises (SMEs) account for 99 percent of the global environmental technology industry. Environmental monitoring and testing is a high innovation and technology-based branch of the industry. This sector is segmented by product type, sampling methods, application sensor types, and deployment mode. On the basis of product type, the market is classified as environmental observation software, environmental monitors, and environmental sensors. Further, the environmental observation segment is bifurcated into fixed and portable environmental monitors. On the basis of the sampling method used by the specific environmental observing technology device, the sector is classified as active monitoring, passive monitoring, intermittent monitoring and continuous monitoring of numerous environmental variables. On the basis of sensors, the market is segmented into various sensor application segments such as physical measures (e.g., temperature, flow, sound), chemical measures (e.g., salinity, dissolved oxygen, hydrocarbons), biological measure (e.g., primary productivity, pathogens, animal tracking) or by mode of measurement (e.g., electrode, acoustic, optical). In addition, it is important to consider the types of platforms for deploying these instruments (e.g., gliders, floats, drifters, autonomous surface vehicles, sleds, autonomous underwater vehicles, and buoys) and other related hardware needed for integrated research, observing and management efforts (from cables and floats to power and communications).

The current size of the global market for environmental monitoring instrumentation is $4.5 billion based on one study (Precisions Reports, 2022). Projections are that the market will reach $7.1 billion by 2028 growing at a compound annual growth rate of 6.7%. Major factors driving the growth include: Increasing awareness of global climate change and rising pollution levels, the development of government regulations to reduce environmental pollution, ongoing installation of environmental monitoring stations, development of environment-friendly industries, and the expansion of climate and pollution monitoring infrastructure. However, high maintenance and operation costs, and technical limitations associated with water monitoring products are major constraints for the expansion of the market.

The environmental technology market is unique in that a major driver is governmental regulation. However, the lack of flexibility in governmental regulations has in many cases limited incentives for developers and manufacturers to explore new innovative instrumentation to improve monitoring capabilities. For example, it has been the US Environmental Protection Agency (EPA) policy is to prescribe specific, very detailed "reference" methods for compliance with the monitoring requirements under each of its major environmental programs. Consequently, instrumentation developers have focused mainly on incremental product improvements instead of investing in more innovative or novel technology approaches. Recently, regulatory agencies have been moving toward allowing the use of performance-based testing methods to replace some of the rigid, highly prescriptive testing methods. Widespread adoption of performance-based testing methods would remove some barriers to innovation. In 2016, the International Organization for Standardization (ISO) published *ISO 14034:2016 Environmental management — Environmental technology verification (ETV)* to standardize the environmental technology verification process at a global level. The standard specifies the requirements for organizations that test and verify the performance of innovative environmental technologies. As the ISO standard becomes established, it is expected that the number of environmental technology companies seeking verification services will increase significantly. However, there is currently only one company in the United States that is accredited to ISO 14034, and private verifications may be cost-prohibitive for many SMEs.

By definition, ***innovative technology*** is new, so it suffers from a distinct disadvantage compared to established technology – ***it lacks the broad acceptance and commercial legitimacy that exists for established technology***. As a result, investors and buyers of environmental technologies prefer to rely on older, established and often verified/certified technologies, rather than take a chance on new innovative solutions. These challenges to "push the envelope" in adopting new technologies within the industry has limited the opportunities for small, entrepreneurial companies to force paradigm shifts in technology.

Independent third-party technology verification and validation (IV&V) is not a new idea. It has long been recognized as an important step in the technology development process to ensure the delivered product satisfies users' operational needs. Verification determines if the technology meets requirements and specifications. Validation determines if the technology does what the user needs it to do. The customer for technology performance information includes technology buyers and users, government regulators, and technology enablers, such as investors. The IV&V data help build vendor credibility and buyer and investor confidence by providing the marketplace with the assurance that the vendors' environmental performance claims of their technologies are valid, credible and supported by high-quality, independent test data. By generating trust, these verified performance claims allow producers to more easily deploy their innovation into the market by:

- Leapfrogging "market signals," by giving prospective users reliable information to allow the innovation to be modelled against competing alternatives. In the event that the innovation turns out to be useful, its adoption can proceed rather more quickly than if users were to await "market signals" of process optimization.
- Unlocking finance for small and medium enterprises which have traditionally been the incubators of innovation yet are often reliant on external funding. By giving investors and financiers a clear picture of the innovation against which to assess their financial decisions, verification can unlock funding and hasten the journey of the idea to the market.

Credible proof of performance also expedites regulatory and permitting approvals.

Academic researchers have evaluated new technologies for ocean instrumentation companies for decades, often as informal, ad hoc studies. The traditional technology testing strategy was a partnership between the researcher and the company through individual research projects. In most cases, the company held proprietary rights to the performance data of the newly developed technology. There were no standardization of testing protocols, little transparency, and minimal quality control and quality assurance. Technology users had to depend on vendors' information on the performance of their instruments.

EPA was the first federal agency to provide third-party assessment of environmental technology when it launched the Environmental Technology Verification (ETV) Program in 1995. The ETV program was carried out through cooperative agreements with private testing and evaluation organizations which included five verification centers. In the beginning, the vendor only contributed towards a small part to the total costs necessary for the verification. The rest was supplied by the government and by other stakeholders. In 2007, US ETV moved to a fully vendor/collaborator-paid program with EPA providing only in-kind technical support. EPA ended ETV operations at the end of 2014. By that time, six other countries and the European Union (EU) initiated some form of an ETV program.

The National Oceanic and Atmospheric Administration (NOAA) initiated the Alliance for Coastal Technologies (ACT) program in 2001 based, in part, on the ETV model. In a statement to the U.S. Commission on Ocean Policy on May 13, 2002, NOAA Administrator Vice Admiral Conrad C. Lautenbacher, emphasized that integration of reliable, efficient, and standardized sensors and sensor platforms into routine collection of environmental data is essential to the success of an U.S. Integrated Ocean Observing System (IOOS).

> "*Operational needs are a key driver for this system. We must also continue to identify key ocean research areas and technological requirements. We need to push the research into an operational capacity for this system. We need to continue to advance the technologies that already are making new observations not only possible, but also economically feasible.*"
>
> *"The implementation and continued development of technologies provides us with a tremendous opportunity to gather much-needed data at a much lower cost. This data will support a backbone for the science-based decision making to which this Administration is committed."*

NOAA recognized that the IOOS must aggressively support research and development on new observing technologies. NOAA also determined that the IOOS should have systems to facilitate the continuous infusion of these new capabilities into its operations in order to enhance efficiency and improve its forecast products. Thus, while independent, third-party technology evaluations have always been one of its cornerstones, it is only one of the services ACT provides in an approach facilitating new innovations that address the many environmental and user needs.

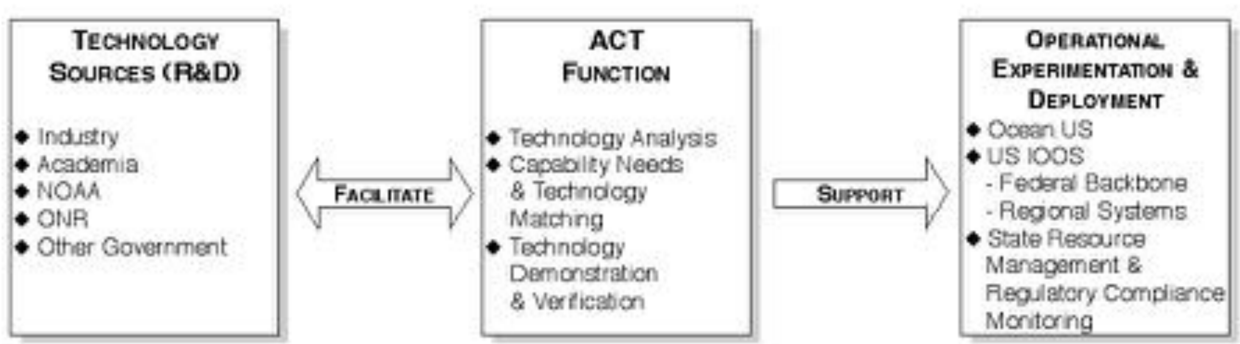

Figure 1. ACT as a broker for technology entry into operational coastal and ocean systems.

ACT provides federal government agencies, e.g., NOAA, the US Geological Survey (USGS), US Coast Guard (USCG) , US Maritime Administration (MARAD), US Environmental Protection Agency (EPA) technology developers, and end-users with a mechanism for transitioning emerging new observation technologies to operational use rapidly, efficiently, and effectively. ACT takes a holistic approach to facilitating new innovations to address environmental concerns, including not just IV&V; but also, market identification and development; consensus and capacity building; and an information clearing-house for the collection, maintenance, and distribution of materials to convey knowledge of existing technologies and technology providers to the user community.

As a "technology broker" (Figure 1.), ACT enables the operational IOOS agencies to implement user-oriented decision-making processes for funding and managing technology development and for linking technology development activities in research institutions and the private sector with IOOS operations. In addition, ACT works with universities and ocean technology companies to quantitatively evaluate alternative technologies, which provides IOOS agencies with information required for the deployment of a cost-effective system of synergistic observing instruments and platforms and to capitalize on technical advances to upgrade its operations on an ongoing basis. ACT also bridges the boundary between science and resource management decision-making, with definite responsibility and accountability to both. In this role, ACT provides multi-directional information brokerage and emphasized long-term trust building and network construction.

In addition to NOAA, ACT received funding from EPA, MARAD, USCG, USGS, US Naval Research Laboratory (NRL), and US Department of Agriculture (USDA) and in-kind contributions from various partners and collaborators. Unlike the US ETV (which ceased operations in 2014) technology developers and vendors participating in ACT evaluations were not charged for demonstrations or verifications. They were only required to provide in-kind support (e.g., staff time, reagents, and test instruments on loan). This funding model provided far more opportunities for broad participation and a more sustainable approach to enabling environmental innovations.

2. THE ACT MODEL

The culture and mission of an organization drives the policies, practices, and processes the organization uses to accomplish an organization's work and moves the organization towards its vision. ACT was created as a true public-private partnership to enable marine technology companies to work with researchers and resource managers, requiring ACT to be responsive to a diverse set of stakeholders. ACT emphasizes creating and sustaining a "true culture of quality" in which ACT personnel not only followed quality guidelines in their work, but also consistently conveyed quality in their interactions with stakeholders and its products.

2.1. Mission

ACT is an environmental innovation enabling, and technology performance testing and verification, organization that combines scientific expertise and input from stakeholders to accelerate market adoption and operational deployment of technology-based solutions by providing credible and quality assured information on technology performance, reducing risk and creating value.

2.2. Vision and Values

Vision - ACT is dedicated to be a reference point and a source of knowledge for environmental technology performance, providing global leadership in revolutionizing environmental monitoring solutions that were innovative, sustainable, robust, and flexible in order to address global environmental change.

Values - ACT is committed to a set of core values that not only defined what it was, but also served as guideposts to help it achieve its vision:

Integrity

- maintain the highest standards of honesty, transparency, credibility, and accountability in our interactions with our stakeholders, partners, and each other;
- conduct all activities in accordance with the highest moral, legal and ethical standards;
- strive for mutual respect and trust in relationships;
- comply with all applicable laws and governmental rules and regulations; and
- ensure protection of confidential and proprietary information.

Stakeholder focus

- maintain a culture dedicated to meeting all of its stakeholders' needs;
- prioritize stakeholder satisfaction as the primary concern for all services;
- develop close relationships with the stakeholder base and be invested in stakeholder success; and
- build stakeholder trust by listening to and exceeding their expectations.

Quality

- conduct all activities and tasks under a quality management system (QMS) that meets international quality standards;
- provide rigorous, unbiased, quality-assured data on technology performance that are fit for their intended uses in operations, decision making and planning;
- utilize the best appropriate technology, methods, and best practices; and
- embed continuous quality improvement in procedures and processes.

2.3. Products and Services

2.3.1. Technology evaluations

ACT technology evaluations are either verifications of commercial-ready and existing commercial technologies or demonstrations of technologies in the early stages of development. All evaluations are conducted under controlled laboratory environments to identify influencing ambient factors and quantify their relation to sensor outputs, and/or in the field at operational sites on deployed equipment. ACT convenes experts and stakeholders worldwide, including representatives of the participating vendors, prior to an evaluation to address the state of the technology and develop the protocols to guide each test. Variations in the content of technology-specific test plans are anticipated, since different technologies have different characteristics and needs. For example, some field sensor technologies had a directly corresponding laboratory method for reference analysis, while others, such as monitoring platforms, required other methods of confirming performance.

The ACT technology evaluation process developed in 2003 is founded on the requirements described in ISO 14034:2016 *Environmental Management - Environmental Technology*

Verification, the new international standard for performance measurement and verification procedures for environmental technologies developed 13 years later. The level of evaluation is determined by the commercial status of the technology.

Commercial-ready and existing commercial technologies are eligible for ACT IV&V. Technology performance is evaluated under controlled laboratory conditions, which allows manipulation of various influencing factors, and/or fully deployed in specific or multiple operational environments to measure the level of effectiveness of the equipment under normal use conditions, using regular operators and maintenance personnel.

ACT Technology Demonstrations are for technologies in the early stages of development (e.g., beta testing or new to the market). An ACT Demonstration follows the same general procedures as a technology verification but involve fewer steps and focuses on highlighting the capabilities and potential of pre-commercial or emerging early-stage technologies, building user awareness, and facilitating technology maturation and transition into operational observing. An ACT Technology Demonstration allows vendors to conduct engineering and other development tasks to evaluate compatibility and interoperability with existing/planned systems and to determine that the equipment/system is ready to proceed to testing in the operational environment. Additional limited developmental testing can be conducted after devices had been fielded to fine-tune their technologies in order to meet operational performance requirements.

ACT establishes priorities for verification activities with the help of stakeholder input. Technologies are selected for IV&V based on: (1) stakeholder consensus that there is a legitimate management and science need for the technology, (2) that there are multiple commercial or near commercial-ready instruments for testing, and (3) that testing is feasible within a reasonable time frame and ACT capabilities and funding. ACT then forms a Technical Advisory Committee (TAC) for each evaluation, enlisting top scientists, natural resource managers, and industry leaders to:

- assist the ACT technical team in developing the test protocols;
- approve the final test protocols;
- provide specific advice during testing;
- review and comment upon draft reports; and
- approve final reports.

ACT next works with stakeholders and the Technical Advisory Committee to identify the verification factors, or performance considerations, about which technology purchasers and regulatory/permitting organizations need information to make decisions. For example, ACT has evaluated monitoring technologies for verification factors such as measurement precision, accuracy, and overall ruggedness of the instrument. Performance parameters specified to be verified in each evaluation were based on whether:

- they were relevant and sufficient for the verification of the performance of the environmental technology, and its environmental added value, if applicable;
- they corresponded in full to the needs of the interested parties;
- they could be quantitatively verified through testing;

- their numerical values could be verified under set operating conditions; and
- relevant technical references existed including standard test methods, preferably international standards.

When the full list of evaluation factors to be verified are identified, ACT develops a test protocol specific to the technology and the performance parameters to be verified. The protocols are developed through direct discussions between ACT personnel, the participating instrument manufacturers and the TAC during Performance Verification Protocol Workshops. The test protocol includes at a minimum:

- a description of the technology;
- a list of performance parameters and the description of how they will be verified;
- technical and operational details of the planned verification;
- specification of the requirements for the test data, including quality and quantity and test conditions; and
- a description of methods for the assessment of the test data and their quality.

ACT tests the equipment using the procedures outlined in the test protocol. The test conditions specified in the test protocol are identical to the operating conditions of the technology. If a technology is tested in the field, the test site(s) are identified so that the protocol could be tailored to a particular test location(s).

All ACT personnel involved in an evaluation are trained on use of instruments by manufacturer representatives and on standardized water sampling, storage, analysis and shipping methods during a training workshop held prior to deployment. The manufacturer representatives and the ACT Chief Scientist verify that all ACT technical staff were trained in both instrument and sample collection protocols. Audits of the test event are conducted by an independent Quality Assurance (QA) Manager. Rigorous quality assurance evaluations of the resulting test data were performed in accordance with the plan and the ACT Quality Management System (QMS).

The results of a technology evaluation are documented in a Verification or Demonstration report. The reports are then announced to technology end-users (through ACT stakeholders networks) and made available for use by the technology developer for securing funding, expanding operations and sales, or entering new markets. The primary form of report distribution is through downloadable pdf files on the ACT website.

ACT evaluation procedures are not a certification scheme. Instead the procedures ensure that a product's performance claims are true and verified, and presents a clear assessment of the technology's environmental potential and value. From beginning to end, every step in the evaluation process is documented and rigorously adhered to. Each step is subjected to pre-established standards and quality controls. This ensures that all evaluations are completed in accordance with existing international standards.

2.3.2. Technology workshops

ACT workshops spark dialogs, facilitate brainstorming, and generate new ideas for technological advancement. Workshops are designed to create community consensus on the state of technology and identify gaps that define development needs and agree on actions to improve the pace of integrating technologies into sustained observing. ACT's interactive workshops stimulate creativity on technological innovation through collaborative working between federal and state resource managers, ocean scientists, and the private sector to decide priorities, strategy, vision, and commitment for building a desired future state of a specific technology. Questions that usually are addressed include:

- What is the current development status of technology?
- What are the trends and drivers affecting development?
- What are the bottlenecks to development?
- What are the key actions needed from different types of stakeholders to address barriers and reach milestones?

Additional questions could include:

- What are the critical technology performance parameters?
- What are the evaluation criteria that technology users can use to determine the suitability and applicability of a given technology for their specific purpose?

The majority of the workshops have a common format, which includes short plenary presentations to provide examples of technology in use for management applications and a series of breakout sessions and open discussions guided by a set of charge questions (based on those listed above) to define recommendations. Each workshop produces a report, which describes the status report of current technologies and recommendations for both ACT and the broader community on steps forward.

These workshops help set the stage for future "follow through" actions by ACT, including: identifying candidate technologies for technology evaluation activities; brokering partnerships of technology developers with public and private research and development (R&D) funding sources; networking technology suppliers with technology users; and prompting follow-up training opportunities for technology users and operational staff of monitoring/observing programs. In addition, workshop recommendations may stimulate proposal and project development and generate funding opportunities through other programs such as the NOAA Small Business Innovation Research (SBIR) Program, National Ocean Partnership Program (NOPP), and Cooperative Institute for Coastal and Estuarine Technology (CICEET).

Workshop themes are selected and developed using information from ACT's involvement with its stakeholders and communications with others involved in ocean observing technology R&D and operations. Each workshop has an organizing committee, which included the Principal Investigator for the respective Partner institution, at least one Stakeholder Council member, and other experts in the topic. The number of workshops conducted each year was reduced following the reduction of available resources.

One of the most significant short-term outcomes from ACT Technology Workshops has been the creation of new communications networks among key members of the community. In fact, several collaborations between academic technology developers and commercial technology vendors have been established during the course of an ACT workshop. Technology manufacturers in particular have also used ACT workshops as a resource to modify and improve technology designs/features to better meet user needs and instrument investment choices by technology users have been influenced.

2.3.3. Outreach and technology diffusion

ACT Outreach activities have a number of goals:
- increase general public awareness and support for ACT;
- involve stakeholders, agencies, and other interested communities in the ACT decision making process to incorporate public values into the program;
- inform technology developers and vendors of priority user needs and requirements, including market potential; and
- communicate available technology solutions to potential technology customers, users, regulators, and policymakers.

ACT is user driven, and a key element of ACT's outreach is the ability to link user types to applications, applications to requirements, requirements to products, and products to observations. ACT outreach and engagement provides valuable face-to-face interactions with leaders in ocean technology business, science, and management and encourage academia-industry-government partnerships, which are critical to emerging technology growth and operational adoption. Examples of these interactive programs include stakeholders' meetings, workshops and conferences, exhibit production, and special events.

The second major focus of ACT's Outreach is publishing, marketing and disseminating the work and activities of ACT in user-friendly formats. ACT has developed a broad array of fact sheets, presentation, videos, posters, reports, and other information materials that collectively describe ACT's services and products, outline the general processes, and provide details about each Technology Workshop and Evaluation. Having multiple types of materials available provides ACT with the flexibility to use different delivery options, depending on the audience's makeup and interests. All these materials were made available on the ACT website.

ACT recognizes that outreach and engagement, i.e., providing "awareness" information alone regarding environmental technology innovations, is inadequate with respect to encouraging adoption. Likewise, verification alone will not move better, cheaper, faster technologies into the marketplace. ACT adopted an "information diffusion" strategy for getting the information directly to federal and state government and industry users in ways that would increase their comfort level in more readily accepting ACT verified technology performance data. Objectives are to:
- develop ACT information products that are compatible with the existing values, past experiences, and needs of potential adopters, "user friendly," and visible;

- facilitate the creation of interpersonal communications networks among the coastal resource management and coastal monitoring communities to share information about ACT verifications and decrease uncertainty about ACT verified data; and
- identify and target early adopters/opinion leaders.

The ACT information diffusion strategy calls for working closely with opinion leaders in the coastal resource management community and developers and suppliers of coastal monitoring instrumentation. Opinion leaders informally influence other individuals' attitudes or overt behavior in a desired way with relative frequency, so they are critical to the successful diffusion of innovations.

2.3.4. Coastal observing technology information clearinghouse

The ACT coastal observing technology clearinghouse was an end-user driven online database that compiled and stored information on coastal observing technology and company information worldwide. It was created to allow environmental observing technology providers and users to match needs in a virtual “marketplace” environment. Key features of the clearinghouse were that it was:

- intuitive – searches could be based on parameter of interest, sensor type, company, or keyword;
- interactive – technology manufacturers could enter and update information, which was reviewed by ACT to ensure data is complete and relevant; and
- up-to-date – information and links were updated regularly by ACT and participating manufacturers.

The content of the database contained records of more than 4,000 instruments and 400 companies in 2019. On each individual record, visitors could : (a) browse a brief overview of the technology, including technical specifications and company contact information; (b) download PDF files of relevant literature provided by the company; (c) link directly to the manufacturer’s website and web page for the sensor; and (d) download Verification or Demonstration Statements for ACT verified instruments as PDF files. A contact phone number or e-mail address was provided if specifications were not available on line. A “compare” function was also built to allow for user assessments of multiple instrument specifications for the same category.

ACT partnered with the USGS and EPA to integrate the ACT database with the National Water Quality Monitoring Council’s (NWQMC) National Environmental Methods Index (NEMI). The goal was to provide access to the individual ACT and NEMI databases from a new web portal (www.nemi.gov/home/) in order to allow for searches of specific environmental parameters that result in listings and documentation on both standard methods and commercial instruments to quantify/measure the parameter of interest.

2.3.5. Needs and use and market assessments

ACT conducts selective needs and use assessments to ensure its activities are focused on the important issues concerning specific technologies in the marketplace. Assessments have been generally designed to determine:

- Who uses the sensors and their main area of interest, research or concern?
- What type of sensor they currently used?
- How they used it, including location/environment, deployment method and time?
- What are the advantages and limitations of the sensors they currently used?
- What were the perceived advantages and limitations of other available sensors they did not use?
- What are the most important performance parameters used to decide which sensor to use/purchase (e.g., reliability, range, accuracy, precision, calibration life, cost, etc.)?

The target sample size is 50 to 100 respondents, representative of a cross-section of the user community, including management, research, and observing community instrument users. Questionnaires are designed to allow for a structured response to provide quantitative data for statistical analysis. The results are published in reports that are used to: (a) identify priority parameters and applications for ACT Technology Evaluations; (b) define the focus and critical questions for ACT Technology Workshops; and (c) supplement specific ACT Workshop conclusions and recommendations. Needs and use assessments also provide valuable quantitative information for the broader coastal communities on current applications of specific technologies (i.e., who uses it, what do they use it for), what users perceive as advantages and limitations of the technology, and what technology users suggest for improvement. All assessment reports are made available to the public through the ACT website as pdf files.

In addition to well defined, documented and understood technology user needs, the ACT Needs and Use Assessments have provided a new line of communication between technology users and technology manufacturers. Manufacturers have stated that they now rely on these ACT assessments for rigorous, relevant and statistically-sound information on how instruments are used and what priority parameters are considered when users select an instrument.

ACT conducted a market assessment of *in situ* nutrient sensors as part of the Nutrient Sensor Challenge (2013-2017), a collaboration with a coalition of federal partners to accelerate the development, production, and use of affordable, reliable, and accurate nutrient sensors. The market assessment had the following objectives:

- to map the current and upcoming applications of these sensors;
- to create a solid understanding of the structure of the market for nutrient sensors; and
- to identify the trends for the future development of the respective market segments as well as the barriers for further development of the market.

The assessment involved both secondary and primary research to collect data. Secondary sources included industry reports, white papers, articles from recognized authors, trade journals, government statistics, and websites. The key players in the market are identified through this secondary research.

The next step was to validate the findings of the secondary research with the experts across the technology value chain through primary research. Examples of primary information sources include focus groups, surveys, and interviews by phone or in-person of stakeholders from both supply and demand sides, e.g., technology providers, government regulatory and research agencies, and R&D institutions. All possible parameters that affect the market for nutrient sensors were accounted for, viewed in extensive detail, verified through primary research, and analyzed to obtain the final quantitative and qualitative data to determine the market size and to estimate growth.

2.3.6. Coordination with other programs

Coordination with federal, regional, and state coastal ocean and freshwater observing programs and other technology demonstration, verification, and certification programs is an ongoing activity in order to monitor progress of these efforts and to explore the potential for collaborative activities. The primary objective is to ensure that ACT activities are not redundant, but rather complementary to, and supportive of, other programs.

ACT has been proactive in forming partnerships at all levels of the observing community, including collaborations with the Ocean Observatories Initiative (OOI), National Water Quality Monitoring Council (NWQMC), National Ecological Observing Network (NEON), and Quality Assurance of Real-Time Ocean Data (QARTOD) to better contribute to the validation and advancement of emerging technologies for global environmental observations

Within NOAA, ACT actively coordinated with the CSC and the IOOS Office, including all eleven IOOS regional associations (RAs) and worked closely with NOAA's Center for Operational Oceanographic Products and Services (CO-OPS), the National Data Buoy Center (NDBC), the Harmful Algal Blooms Observing System (HABSOS), the Ocean Acidification Program, the Sea Grant College Program, and other offices, centers, programs, and laboratories.

Other US federal agencies that partnered with ACT include EPA, USGS, MARAD, USDA, USCG, the National Institute of Standards and Technology (NIST), the National Science Foundation (NSF), the Army Corps of Engineers (USACE), and the Bureau of Ocean Energy Management, Regulation, and Enforcement (BOEMRE).

At the state level, ACT coordinated with most states' natural resources and environmental agencies in which ACT conducted technology evaluations and other activities, such as the Maryland Department of Natural Resources (DNR) and the Southern California Coastal Water Research Project (SCCWRP).

ACT also has worked with non-profit organizations, such as the Prince William Sound Oil Spill Recovery Institute in Alaska and the Everglades Foundation.

Federal and state managers and scientists have served on all technology evaluation advisory panels and participated in every ACT technical workshop.

Internationally, ACT has worked with groups including: the European Global Ocean Observing System, Joint Commission for Oceanography and Marine Meteorology, Venice Water Authority, National Oceanography Centre (NOC), Southampton, French Institute for Exploitation of the Sea, Korean Ocean Research and Development Institute, the Bedford Institute of Oceanography, Nova Scotia, and others to foster global efforts to identify and adopt appropriate, standardized technologies for operational coastal monitoring and oceanographic systems.

2.4. Quality management

The ultimate success of an environmental technology verification program depends on the quality of the data collected and used in decision-making. ACT is committed to quality. ACT adopted the philosophy that its technology performance data and information must be of known quality; the results meet the expectations of their intended use, and the data must be appropriately documented and scientifically defensible. ACT infuses quality assurance/quality control (QA/QC) into the way it conducted all its activities. This "culture of quality" drove the policies, practices, and scientific processes that ensured that performance data of known quality, meeting the quality objectives of the test and test methods and the user's requirements, are consistently produced to reduce risk and uncertainties in technology selection and use by end users.

To build this philosophy into policy and operations, ACT adopted voluntary national and international consensus standards for quality such as the American National Standard Institute/American Society for Quality Control -- ANSI/ASQC E4-1994, ISO/IEC 17025 *General Requirements for the Competence of Calibration and Testing* Laboratories, and USEPA standards when developing and implementing its QMS. Multiple Technical Systems Audits (TSAs) have been conducted on every ACT technology evaluation in accordance with the procedures described in EPA's *Guidance on Technical Audits and Related Assessments for Environmental Data Operations* (EPA QA/G-7) [EPA, 2000]. Audits included a review of staff, test procedures (sample collection, sample analysis, data processing, etc.), facilities, and documentation.

Review of test data is conducted to ensure that only sound data that are of known and documented quality and meet ACT technology verification quality objectives are used in making decisions about technology performance. ACT's data review processes are based in part on two EPA guidance documents: *Guidance on Environmental Data Verification and Data Validation* (QA/G-8) [EPA, 2002] and *Guidance on Technical Audits and Related Assessments for Environmental Data Operations* (QA/G-7) [EPA, 2000]. Data are verified and validated to evaluate whether the data have been generated according to the Test Protocols developed for the evaluation, satisfy acceptance criteria, and are appropriate and consistent with their intended use of evaluating the performance of the test sensors. Data verification evaluates the completeness, correctness, and consistency of the data sets against the requirements specified in the Test Protocols, measurement quality objectives (MQOs) in the ACT Quality Assurance Project Plan (QAPP), and any other analytical process requirements contained in standard operating procedures (SOP).

3. HISTORICAL PERSPECTIVE: CREATING A FRAMEWORK FOR ADVANCING OCEAN TECHNOLOGY INNOVATION

3.1 Origin and first steps (1998 – 2003)

ACT began with studies commissioned by the NOAA Coastal Services Center (CSC) in 1998-1999 to assess the usefulness of a technology verification system for coastal managers and ocean technology companies. These studies 1) confirmed that coastal managers had an important need for objective information on the performance on *in situ* sensors and systems for monitoring coastal waters and 2) proposed a networked "co-laboratory" organizational structure consisting of a headquarters unit to coordinate all program activities and partner marine institutions distributed throughout the country to conduct laboratory and field tests in a variety of marine environments and regional outreach.

CSC launched ACT in 2000 through a Cooperative Agreement with the University of Maryland Center for Environmental Science Chesapeake Biological Laboratory (CBL). ACT was structured around "Partner" marine science institutions located throughout the U.S. A headquarters office is located at the CBL to coordinate and oversee all ACT products and activities.

There were originally (2001 - 2010) eight ACT Partner institutions (Fig. 2), with coastal technology expertise that represented a broad range of environmental conditions for instrument testing:

- University of Maryland Center for Environmental Science (UMCES), Chesapeake Biological Laboratory (CBL), Solomons, MD;
- Skidaway Institute of Oceanography (SkIO), Savannah GA;
- University of Hawaii School of Ocean and Earth Science and Technology (SOEST) / Hawaii Institute of Marine Biology (HIMB), Kaneohe, HI;
- Moss Landing Marine Laboratories (MLML) and Monterey Bay Aquarium Research Institute, Moss Landing, CA;
- University of Michigan and the Cooperative Institute for Great Lakes Research (UM/CIGLR) formerly the Cooperative Institute for Limnology and Ecosystem Research (UM/CILER), Ann Arbor, MI;
- University of South Florida (USF), St Petersburg, FL;
- University of Alaska Fairbanks, (UAF) Fairbanks, AK, and Alaska SeaLife Center (ASLC), Seward, AK; and
- Gulf of Maine Ocean Observing System (GoMOOS); Portland. ME.

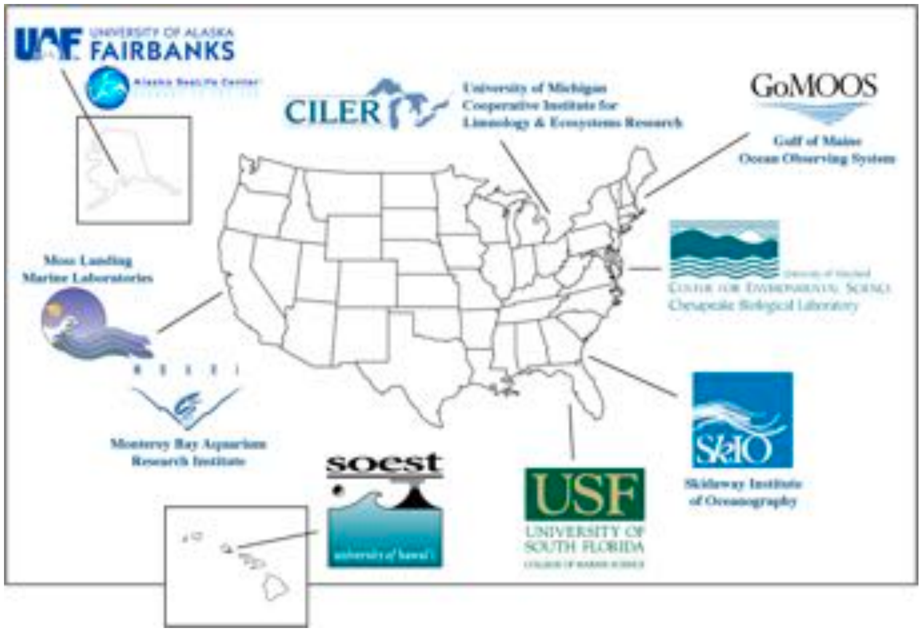

Figure 2. Original ACT partner institutions 2001-2010.

3.1.1. Partners

The nationally-coordinated, regionally-distributed ACT Partners enables ACT to be more relevant to specific local priorities and to more effectively serve a wider array of users. Common capabilities of all of these original ACT Partners included having:

- extensive experience in developing and operating sophisticated systems for research and monitoring of a variety of aspects of the coastal ocean and freshwater environments;
- skilled scientists, engineers, and operations staff with extensive qualifications for developing, adapting, and servicing multidisciplinary coastal observing technology;
- established engineering standards and quality controls;
- state-of-the-art on shore facilities and equipment to support physical and biological oceanographic research;
- infrastructure to support offshore marine observing operations, including ships, platforms, divers, etc.; and
- extensive experience and qualified staff for education, outreach, and technology transfer.

The original ACT Partners were strategically located to permit concurrent verification of diverse sensor applications across a wide range of coastal environments, including estuaries, bays, shorelines, continental shelves, coral reefs, and the Great Lakes and/or environmental conditions (e.g., freshwater to open ocean, tropical to high latitudes). Also, the geographical diversity of the ACT Partners created greater flexibility for ACT to respond to changing regional priorities and maintain pace with and adapt as new capabilities and technologies become available. Finally, the regionally distributed system facilitated greater direct access and participation of a broader group of stakeholders in ACT functions.

3.1.2. Stakeholders

ACT created a Stakeholders Council that consisted of representatives recruited from the greater environmental monitoring community, including private sector companies and environmental management agencies. The Council members participated in ACT planning and decision making, such as assisting in prioritizing the types of technologies to be verified, assisting in development of generic verification protocols, reviewing technology-specific procedures and selected ACT reports emerging from ACT verification activities, and assisting in the definition and conduct of outreach activities appropriate to the technology area and customer groups.

3.1.3. Alliance Members

ACT also formed an Alliance Members advisory group, which allowed institutions, companies, and organizations involved in the development and/or use of coastal sensor technologies to interact and collaborate with ACT, to keep abreast of ACT activities, to help develop themes of the invitational ACT Workshops, and to foster the interactive flow of ideas and information among the various developers/users of sensor technologies for use in coastal monitoring. The Alliance was organized regionally under the leadership of the ACT Partners and nationally through the representation of the Stakeholder Council.

3.2. Pilot period

A workshop held at CBL in October 2000 initiated a broad based stakeholder process to identify priority products and services. A pilot period (May 2001 – April 2003) established and documented, how ACT would function, how specific tasks would be performed, and how specific products or services would be provided to ACT customers. The four-pronged strategy for technology transition included 1) verifications of commercial-ready and commercial technologies and demonstrations of prototypes; 2) cross-sector, technical workshops and customer needs assessments to assess the current state-of-the-art in technologies; 3) an online searchable database of available technologies; and 4) outreach, including web-based media and Regional Alliance Member chapters. The latter was a larger stakeholder organization that was created as part of ACT's outreach and technology diffusion activities to foster the interactive flow of information and ideas among a broad range of user groups and disciplines.

During this pilot period, ACT developed the *ACT Guidelines for Technology Evaluations* and *ACT Quality Assurance Guidelines*, which were the two major documents that defined the overall operation of ACT technology verification activities. The *ACT Guidelines for Technology Evaluations* describes the goals, customer and key word definitions, basic operating principles, technology selection criteria, inter-organizational relationships, generic laboratory and field test methods and data collection procedures, and communication of test results that will be applied in ACT technology demonstration and verification activities. The *ACT Quality Assurance Guidelines* describes a basic set of mandatory specifications and non-mandatory guidelines that will assure the quality of both the data and the programmatic elements of ACT technology verification activities.

In addition, ACT conducted a "trial" technology verification study to evaluate manufacturer claims regarding the Chelsea Instruments' Mini*tracka* Fluorometer between November 18, 2002 and March 14, 2003. The purpose of the trial verification test was not to evaluate the performance of the fluorometer per se, but rather to fine tune the ACT evaluation process and to identify any procedural problems before initiating a true ACT Evaluation. Thus, the trial was conducted in accordance with the specifications and guidelines that would be applied in future, bona fide ACT technology verifications. Lessons learned from the experiences of all participants in the test were incorporated into the procedural and process elements of the ACT technology evaluation system.

From these beginnings emerged the "ACT Model," described in the previous section. In the following years., ACT distinguished itself by a commitment to continuous improvement of its products, services, and processes.

3.3. NOAA CSC Coastal Observation Technology Systems (COTS) 2003 - 2007

With its organizational and operational structure in place, ACT began full implementation of all program activities in May 2003. ACT functioned as a part of NOAA's Coastal Observation Technology Systems (COTS), a coalition of seven programs located along the Pacific, Gulf of Mexico, and south and north Atlantic coasts that focus on coastal ocean observation, research, technology and prediction. The NOAA CSC was the lead federal coordinating partner for COTS, which was to serve as a model for a national IOOS.

During this period, ACT conducted the first technology evaluation on dissolved oxygen sensors. Technology evaluations were conducted at all ACT Partner sites. A series of technical workshops were implemented by the full suite of ACT Partners.

3.4. NOAA NOS Integrated Ocean Observing System (IOOS) 2008 - 2020

In 2009, NOAA transferred administration of the Cooperative Agreement for ACT to the NOAA's IOOS Office with a request that ACT products and services become more directly focused toward specific needs of IOOS and the IOOS Regional Associations (RAs). ACT made a number of organizational and functional changes to sustain productivity under IOOS and with the resources made available. ACT restructured its organizational model for program base-support and also an importance of focusing ACT products and services more directly toward specific technology "themes," i.e., priority needs of the ocean observing community. The composition and the number of permanent "core" ACT Partners was adjusted to adapt to these changes. GoMOOS, SkIO, and ASLC voluntarily ceased direct participation in ACT operational activities in 2010. GoMOOS was incorporated in to the Gulf of Maine Research Institute and no longer operated as an ocean observing program. SkIO did not continue partly due to some degree of overlap of environments for testing with other Partner sites. UAF and USF withdrew as full Partners in 2013 and 2017, respectively. The University of Louisiana Lafayette (ULL) joined as a full Partner in 2015 and has played a significant role in verifications and workshops on nutrients, HABs, and eDNA. Otherwise, rather than adding more permanent Partners, ACT invited several institutions and agencies to participate as "affiliate" ACT Partners. Affiliate Partners join ACT as Co-PIs and receive task-specific funding in support of specific technology themes, based on their interest and ability to provide expertise and resources. Activities are conducted by a mixture of Core and Affiliate ACT Partners. Affiliate Partners include:

- Northeastern Regional Association of Coastal and Ocean Observing Systems (NERACOOS), hyperspectral imaging, drones (2016 – 2020);
- Michigan Technological University (MTU), hypoxia/dissolved oxygen (2015 - 2016);
- United States Geological Survey (USGS), nutrients (2016 – 2022);
- University of California Santa Cruz (UCSC), HABs and HABs toxins (2016 -2018);
- Bowling Green State University (BGSU), HABs and HABs toxins (2016 – 2018);
- NOAA Great Lakes Environmental Research Laboratory (GLERL), hyperspectral imaging (2018 – 2022);
- Bermuda Institute of Ocean Sciences (BIOS), hyperspectral imaging (2018 – 2022);
- Maritime Environmental Research Center (MERC), total residual oxidant (TRO) analyzer verification (2019);
- Great Ships Initiative (GSI), verification of ballast water system compliance monitors (2015-2016); and
- Smithsonian Environmental Research Center (SERC), verification of ballast water system compliance monitors (2015-2016).

MERC, GSI, SERC, and USGS personnel directly participated in ACT evaluations, but these Affiliate Partners did not receive any NOAA funding through ACT.

ACT assembled "tiger teams" (i.e., specialists assembled to work on a specific technology evaluations) of technical staff from multiple ACT Partners to conduct technology evaluations and utilized test sites in conjunction with ongoing monitoring efforts. For example, in the demonstration of algal toxin detection field technologies, kits were tested at three fixed dockside stations on Long Island, NY. These stations were being sampled weekly by Dr. Christopher Gobler's laboratory (Stony Brook University) as part of the New York's Department of Environmental Conservation shellfish monitoring program. The evaluation was conducted by a team consisting of technical staff from Partners MLML, UM/CIGLR, and HIMB; and Affiliate Partners BSGU, ULL, and UCSC.

During the time period of 2007 to 2022, ACT conducted 280 technology evaluations and 14 technical workshops (see the ACT website for complete lists).

4. THEME-BASED APPROACH TO EVALUATIONS

After extensive interactions with its stakeholders, ACT adopted a theme-based approach whereas ACT's suite of products and services are connected together and integrated on specific priority topic areas or issues which are characterized by their wide geographic scope, e.g., regional or global; and on those technological solutions to address the most pressing problems of anthropogenically mediated deterioration of coastal and ocean systems (Appendix 2). There are several key themes that emerged regarding the need to advance the adoption and use of innovative technologies that ACT chose to conduct multiple activities over long periods of time. These themes include:

- ocean acidification;
- nutrient pollution;
- harmful algal blooms; and
- hypoxia.

In addition to these long-term initiatives, ACT maintains flexibility to respond rapidly to new environmental threats, such as ships' ballast water introductions of nonindigenous species (compliance monitoring devices for regulatory enforcement), environmental emergencies, such as the Deepwater Horizon oil spill (hydrocarbon sensors), or agency requests, such as the development of *A National Observational Wave Plan* with US IOOS, NDBC, and the USACE. and the eDNA workshop series requested by IOOS.

The following sections include 1) a description of the environmental issue, 2) an overview of ACT activities implemented to address the issue, and, 3) to the extent possible, actual or potential outcomes from the evaluation.

All technology evaluation reports can be found on the ACT website. Each product-specific evaluation report includes a complete description of the technology, test methods, and performance data as verified by ACT with complete data on the performance. Technical workshops reports, needs and use assessments, market assessments, and test protocols also are posted on the website.

4.1. Long-term ACT Initiatives

4.1.1. Theme: Ocean Acidification

Background - The continual production of anthropogenic carbon dioxide from the burning of fossil fuels is increasing CO_2 gas in the atmosphere and, by absorption to the ocean, acidifying waters around the world. Ocean acidification has become one of the most significant and urgent issues facing ocean resource harvesters and managers. There was a need for improving the spatial and temporal resolution of ocean sampling and monitoring programs of ocean acidification; and these improvements would require the ongoing development of underwater platforms and sensors to measure keystone variables of the marine inorganic CO_2 system.

Activities - ACT has implemented two technology evaluations and conducted two workshops addressing technological issues to monitoring and responding to ocean acidification.

In February 2005 ACT held a workshop on *In-situ measurement of dissolved inorganic carbon speciation in natural waters: pH, pCO_2, TA and TCO_2*. Two recommendations from the workshop were:

- Increase measurements of pCO_2 in coastal waters to better quantify CO_2 fluxes in coastal environments, not just open-ocean environments. These data need to be coordinated with other spatially dependent physical and biogeochemical information.
- Verify that *in situ* pCO2 sensing works within a broad range of environments as prescribed with comparison and availability.

In 2010, ACT conducted a performance demonstration of pCO_2 analyzers (specific instruments listed on ACT website) at two coastal sites, a coral reef in Hawaii, and Hood Canal Washington. ACT evaluated four commercial pCO_2 instruments that are capable of being deployed for weeks to months. The objectives of this performance demonstration were: (1) to highlight the potential capabilities of *in situ* pCO_2 analyzers by demonstrating their utility in two different coastal environments, a vertically stratified sound and a shallow coral reef; (2) to increase awareness of this emerging technology in the scientific and management community responsible for monitoring coastal environments, and (3) to work with instrument manufacturers that are presently developing new or improved sensor systems, by providing an opportunity for thoroughly testing their products in a scientifically defensible program, at relatively minor costs in terms of time and resources to vendors. Field tests were designed to provide data to evaluate accuracy, precision and stability:

(A) (B)

Figure 3. pCO2 sensor field test sites. (A) Hood Canal east of Union, Washington; the PMEL-MAPPS instrument is in the buoy and the other test instruments are mounted about 1 meter below the surface. (B) Kaneohe Bay, northeast side of Oahu, Hawaii; the PMEL-MAPPS instrument is on the buoy and the other test instruments are mounted about 1 m below the surface.

ACT then followed the pCO_2 analyzers demonstration with a performance verification of pH sensors in 2012-2014.   The protocols used for this performance verification were developed in two pH Sensor Performance Verification Protocol Workshops held on June 18-12, 2012 and

June 26-28, 2013 in Ann Arbor, MI. The instrument performance parameters were accuracy, precision, calibration stability and reliability. The verification of *in situ* pH sensors was implemented in two separate test components. The first component involved extended laboratory/mesocosm tests conducted over 2-3 months, under well-controlled conditions designed to minimize biofouling while covering a broad range of water temperatures, salinities, and pH. The second component involved field-based deployments of 2-3 month duration.

The laboratory test was conducted at HIMB. The test was conducted in a single tank that accommodated all instruments (Figures 4-5).

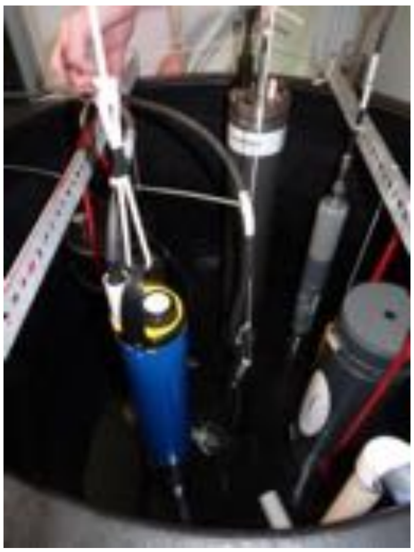

Figure 4. Instrument deployment in test tank.

Figure 5. Spectrophotometric Lab with tank intake.

Moored field tests were conducted at four ACT Partner Institution sites covering freshwater, estuarine, and open-ocean conditions. The test sites included Moss Landing Harbor, CA (MLML), Kaneohe Bay, HI (HIMB); Patuxent River, MD (CBL); and Muskegon Lake, MI (CILER).

Figure 6. Sampling at deployment buoy in Kaneohe Bay, HI.

Figure 7. Duplicate sampling at Patuxent River, MD.

A total of eight sensors from seven participating companies were evaluated during this verification, there were a total of 39 distinct instrument evaluations (laboratory and field) of the four key performance factors.

Outcomes - One of the participants in the verification, Sunburst Sensors, LLC, won first place for both accuracy and affordability in the $2 million 2015 Wendy Schmidt Ocean Health XPRIZE http://www.sunburstsensors.com/news/sunburst-news/33-xprize-4.html, a competition challenging international teams of scientists and engineers to create groundbreaking pH sensor technology capable of transforming the ability to monitor ocean acidification caused by global warming https://www.xprize.org/prizes/ocean-health. Another vendor's instrument, the Xylem pH sensor, was one of the five sensor finalists https://www.ysi.com/about/news/2015/team-xylem-top-five-finalist-of-prestigious-global-xprize-competition.

Eureka's Manta water quality sonde was also evaluated in this verification. These sondes have been successfully deployed in lakes, rivers, estuaries, streams, ponds, and near-shore oceanographic waters, in all 50 states and overseas. Two Eureka Manta2 water-quality multiprobe sondes were tested at the USGS Hydrologic Instrumentation Facility (HIF) in 2017 (Tillman, 2017). The Manta2 pH sensors met the USGS National Field Manual for the Collection of Water-Quality Data (NFM) recommendations and manufacturer's accuracy specification for nominal pH values of 10 and lower (https://pubs.usgs.gov/of/2017/1118/ofr20171118.pdf).

Satlantic combined with Sea-Bird Electronics and WET Labs in 2011 to form a new entity, Sea-Bird Scientific, and introduced the SeaFET™ V2 in 2018 https://www.seabird.com/seafet-v2-ocean-ph-sensor/product?id=54627921732, an upgrade to the ACT-tested Satlantic SeaFET™ pH sensor. The upgraded instrument incorporates the same housing as the original SeaFET™ with improved electronics and new operating characteristics for enhanced stability and reliability in long-term deployments. Deep water versions are now also available. A subsequent evaluation of the SeaFET™ corroborated ACT's findings from its evaluation of the accuracy of the sensor (Miller et al, 2018) in Alaskan waters.

In March 2014, ACT conducted a workshop, *Science Assessment of Chesapeake Bay Acidification: Toward a Research and Monitoring Strategy*, to lay the foundation for establishing a Chesapeake Bay Acidification Network. The workshop helped to put into motion a series of actions by the state of Maryland to address ocean acidification in the Chesapeake Bay. In July 2014, the Maryland General Assembly formed the Maryland Ocean Acidification Task Force to evaluate the science around acidification and potential impacts to Maryland resources and provide recommendations for mitigation strategies. The Task Force produced a final report of their findings in January 2015. These findings served as a basis for the *Maryland Ocean Acidification Action Plan 2020,* which was developed by the Maryland Departments of Environment and Natural Resources in partnership with UMCES (https://mde.maryland.gov/programs/Air/ClimateChange/MCCC/STWG/OA%20Action%20Plan.pdf).

4.1.2. Theme: Nutrient Pollution

Background - Nutrient pollution is one of the world's most difficult environmental challenges. Nutrients are essential compounds for functioning ecosystems and the production of food, fiber, and livestock feed. However, excessive nutrient levels can dramatically alter aquatic environments and can lead to harmful algal blooms (HABs) and hypoxic conditions or "dead zones" in freshwater and coastal environments, as well as human health effects. The search for solutions to these problems resulted in a significant demand for methods to measure in-water nutrients to support scientific research, monitor water quality, estimate safe maximum nutrient loads, determine acceptable discharge standards, set discharge limits, predict hypoxia, assess progress towards meeting nutrient reductions goals, and comply with regulation-driven reporting requirements. *In situ* nutrient sensors offer two fundamental advantages over traditional discrete sampling approaches: (1) data are collected at a much higher temporal frequency; and (2) data can be disseminated in real time (Pellerin et al., 2016). Current nutrient sensor technology has made significant advancements, but the high cost and effort required to purchase, operate, and maintain such sensors has been prohibitive for managers and modelers interested in continuous, real-time nutrient measurements that are required to assess, compare, and validate the effectiveness of nutrient management options.

Activities - ACT has implemented two technology evaluations and conducted two workshops addressing technological issues related to real-time monitoring of nutrients and responding to nutrient pollution.

In 2003, the participants of the ACT workshop on *State of Technology in the Development and Application of Nutrient Sensors* met to summarize what types of *in situ* nutrient sensors were available, to make strategic recommendations for the future development of these sensors for coastal monitoring, and to identify major impediments to the application of new sensors. Among the topics addressed at this workshop were characteristics of "ideal" *in situ* nutrient sensors, particularly with regard to applications in coastal marine waters.

In 2006, ACT held a second workshop, *Recent Developments in In Situ Nutrient Sensors: Applications and Future Directions*, focused on existing commercial solutions. The number of available commercial systems had expanded since 2003, and there was a consensus for the need to expand application and further develop these technologies. This included discussion of possible refinements for sustained deployments as part of integrated instrument packages and means to better promote broader use of nutrient sensors in observing system and management applications.

During May – October 2007, ACT conducted a demonstration of four *in situ* nutrient sensors at four sites in moored, vertical profiling, and surface mapping applications. For example, several of the *in situ* nutrient analyzers demonstrated an ability to accurately track nitrate and phosphate during one-month coastal field deployments, indicating that they would only require minor engineering adjustments for routine, long-term deployments in monitoring or observing networks.

In 2013-2017 ACT collaborated with a coalition of federal partners (including NOAA, IOOS, EPA, USGS, USDA and NIST) and the White House Office of Science and Technology Policy (OSTP), to carry out a multi-year Nutrient Sensor Challenge. The goal of the market stimulation Nutrient Sensor Challenge was to accelerate the development, production, and use of affordable, reliable, and accurate nutrient sensors to enable automated and high-resolution nutrient monitoring in aquatic environments. The Nutrient Sensor Challenge was launched formally on December 17, 2014 (Table 2) in a keynote speech at the American Geophysical Union (AGU) by the NOAA Administrator, Dr. Kathryn Sullivan.

Table 2. Nutrient Challenge Timeline.

Planning	
Visioneering meeting	November 2013
Nutrient Sensor Challenge Workshop	September 2014
Registration	
Challenge registration opens	December 2014
Challenge registration closes	March 2015
No-Risk Beta Testing (Optional)	
Beta testing plans, locations, and schedules released	June 2015
Preliminary Overview of Markets for Challenge-based Nutrient Sensors report	June 2015
Challenge Summit	August 2015
Beta testing at Sites A-C	August – October 2015
Verification	
ACT application deadline	December 18, 2015
Protocol Workshop for verification testing	February 2016
Laboratory verification testing	April 2016
Field verification testing at Sites D-F	May – September 2016
Judging and Awards	
Final verification reports published, awards announced	February 2017

The first event held by the challenge was the Nutrient Sensor Challenge Summit in August 2015. This was an opportunity for 29 registered teams to convene to discuss, learn, network and demonstrate their abilities. Following the summit, no-risk beta testing began. This phase of testing was an opportunity for the teams to take advantage of no-cost, no-risk laboratory and field testing as an important milestone towards final verification testing in 2016. ACT hosted teams for no-cost beta testing of their prototypes. Four organizations submitted six instruments for the verification, three nitrate sensors and three phosphate sensors. Two of the participants submitted integrated systems with both types of sensors.

The Nutrient Sensor Challenge was similar to all past ACT technology verifications in that instrument performance was evaluated in laboratory and field tests against reference water samples analyzed using EPA-approved standard methods. Unlike previous ACT technology verifications, however, results from these verification tests were used by an independent Challenge judging panel in order to address all of the requirements of the competition.

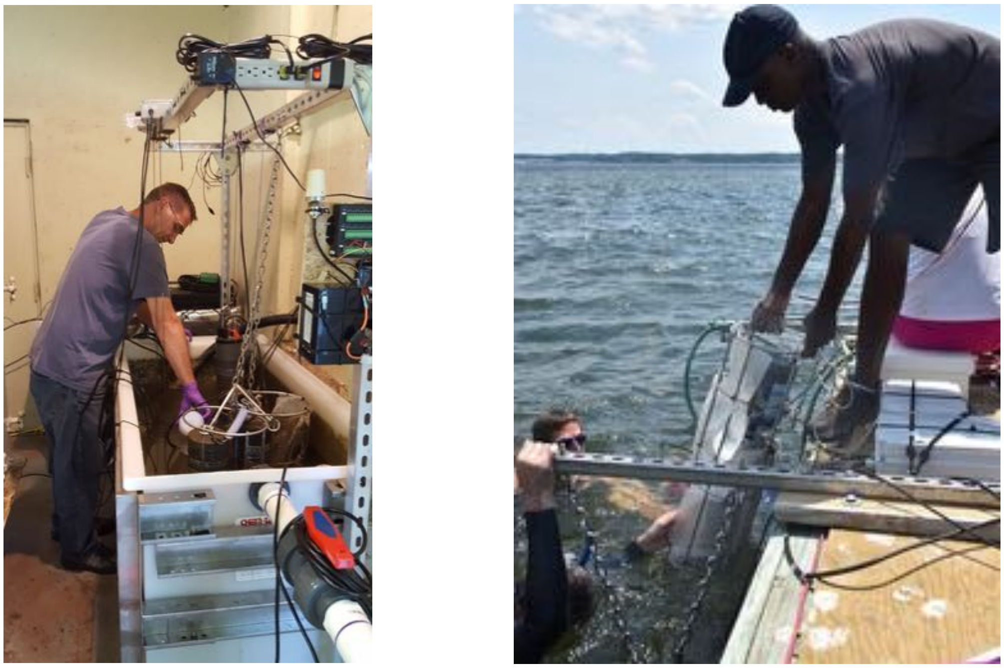

Figure 8. Maumee River flow through deployment tank (left) and Patuxent River mooring (right).

Figure 9. Kaneohe Bay instrument rack.

Figure 10. Pre- and post-deployment at CBL showing extent of bio-fouling.

Outcomes - The winners of the Nutrient Sensor Challenge were announced at a special awards session at the Association for the Sciences of Limnology & Oceanography Aquatic Sciences (ASLO) meeting in Honolulu, Hawaii, on March 2, 2017. The independent judging panel selected Systea S.p.A as the winner in both the nitrate and phosphate sensor categories. Their instruments represent a cost-effective, commercially available solution for measuring both nutrients in an integrated package. An Honorable Mention for innovation and potential was also awarded to the National Oceanography Centre (NOC) team whose work represents a fundamentally new approach to the wet chemical *in situ* analyzer method, using chip-based microfluidics technology. Their sensor also was forecasted to be near the goal for purchase price.

EPA purchased two of the Systea sensors configured for N as nitrite and nitrate and P as phosphate in 2018 (Lindquist at al., 2021). One sensor was installed at the drinking water treatment plant intake structure on Lake William H. Harsha, Clermont County OH, and another on the Lower Merrimack River in Massachusetts.

NOAA through ACT and the Gulf of Mexico Coastal Ocean Observing System (GCOOS), and EPA helped fund the purchase of five (5) of the Systea sensors as part of the Gulf of Mexico Nutrient Sensor Pilot Project to evaluate the "operational status" of newly commercially available nutrient sensors through integration into existing monitoring programs. The pilot project is led by researchers at University of Louisiana at Lafayette, coordinating with partners at the University of Texas Marine Science Institute, the Louisiana Universities Marine Consortium, Dauphin Island Sea Lab, Sanibel-Captiva Conservation Foundation, and the USGS in Tampa Bay.

NOC, with funding from the UK government, has optimized the performance of its "Lab-On-Chip" sensor technology for the measurement of nutrients and micronutrient on autonomous vehicles. There have been a large number of successful deployments in a wide range of settings, from coast to deep ocean through the *AutoNutS: Autonomous Vehicle Nutrients Sensors* project. These include seven AutoNutS sensors onboard Autosub Long Range and one integrated with a Teledyne Webb Slocum glider for the Oceanids trials in Loch Ness in 2019. The NOC development team continue to work on improvements to the technology, including revision of the platform technology to include new low power valves as well as faster measurements (NOC, 2020).

4.1.3. Theme: Detecting Harmful Algae and Their Toxins

Background - Anderson (1989) and Hallegraeff (1993) first outlined the rise in frequency, magnitude and geographical extent of HABs and their impacts during prior decades. HABs are a continued threat to economies and marine/freshwater and human health throughout the US, including coastal regions encompassing the Pacific, Gulf of Mexico, Southeast Atlantic, Northeast Atlantic, and the Great Lakes.

Monitoring efforts and long-term data sets are invaluable for developing strategies for prevention and mitigation of events such as these (Kudela et al. 2015). As noted by Jewett et al. (2008), "To be useful to HAB management, observing systems must be located in areas where HABs frequently occur and must have sensors capable of detecting HAB cells and toxins and monitoring the environmental conditions that foster blooms. They must deliver integrated data sets that can be used in operational mode for forecasting HAB events."

Activities - ACT convened four workshops and conducted three technology evaluations on technologies to detect and monitor harmful algae and algal toxins (Table 3). The workshops set the stage for the technology evaluations, which included 2 verifications and one demonstration spread across 13 years (2005 – 2018). A total of seventeen sensors and test kits were evaluated in laboratory and field tests. There were 163 distinct technology evaluations. Reports providing full descriptions of the technology workshops and evaluations are posted on the ACT website.

Table 3. Timeline of ACT activities on HABs and HAB toxins.

DATES	ACTIVITY	
Mar. 2002	**Workshop:** *Biosensors for Harmful Algal Blooms*	34 participants
Feb. 2005	**Workshop:** *Application of in situ Fluorometers in Nearshore Waters*	36 participants
May – Sept. 2005	**Verification:** *In situ* chlorophyll fluorometers	Customer Needs and Use Assessment; Test Protocols; Laboratory test and field evaluations at 7 sites; 8 instruments; 63 distinct evaluations.
Oct. 2008	**Workshop:** *Technologies and Methodologies for Detecting Harmful Algae and Their Toxins*	45 participants
Feb. 2017	**Workshop:** *Sensors for Monitoring of Harmful Algae, Cyanobacteria and Their Toxins*	54 participants
June - Nov. 2017	**Verification:** Multi-spectral Fluorometers to Detect Harmful Algae and Cyanobacteria	Test Protocols; Laboratory test; Five different field evaluations incl. three underway surface mapping cruises and two moored deployments; 4 instruments; 28 distinct evaluations.
Feb-Oct. 2018	**Demonstration:** Algal Toxin Detection Field Sensors and Kits	Test Protocols; Laboratory tests at marine and freshwater sites; field evaluations at 4 freshwater sites and two ocean sites (the Long Island marine site included discrete sampling from 3 different sites); 5 sensors and test kits; 22 distinct evaluations.

ACT conducted its first technology specific workshop in March 2002 on *Biosensors for Harmful Algal Blooms*. A second workshop on technologies for monitoring HABs, *Applications of in situ Fluorometers in Nearshore Waters*, was held in February 2005. The purpose of these workshops was to discuss the use of fluorometric measuring technology to estimate biomass and the rate of primary productivity in nearshore environments. and the potential for its use by coastal managers to fulfill their regulatory and management objectives.

Six companies submitted instruments for testing for the 2005 chlorophyll fluorometer verification; two of these companies submitted two different sensors. At the time of the verification, chlorophyll measurements were being widely used by marine and freshwater water resources managers and researchers to determine phytoplankton abundance, distribution, biomass, standing crop, and primary production. There were a variety instruments commercially available, and technological improvements were continuing at a rapid pace. The verification helped set the stage for the development of a new generation of fluorometers capable of providing autonomous, instantaneous, non-destructive, and sensitive observations of phytoplankton photosynthetic physiology. (Shuback et al., 2021).

By 2008, the critical importance of monitoring both species and algal toxins had been highlighted in a variety of national and international reports. Two reports submitted to Congress in response to the 2004 reauthorization of the Harmful Algal Bloom and Hypoxia Research and Control Act make a strong case for the development, design, and integration of HAB cell and toxin sensors into observing systems (Jewett et al., 2008, Lopez et al., 2008). One of the key recommendations of the ACT workshop *Technologies and Methodologies for Detecting Harmful Algae and Their Toxins* convened in October 2008 was the need for *in situ* sensors to measure HAB toxins.

An ACT workshop *Sensors for Monitoring of Harmful Algae, Cyanobacteria and Their Toxins* held on January 30 – February 1, 2017 was a follow-up to the 2008 HAB detection workshop. The goal of the 2017 workshop directly aligned with the mandate of the Harmful Algal Bloom and Hypoxia Research and Control Act (HABHRCA, authorized by Congress in 1998, giving NOAA the primary responsibility to advance the scientific understanding and the abilities for HAB event detection, monitoring, assessment and prediction. The workshop reiterated the recommendation of the 2008 workshop for the need to develop HAB toxin detection technologies.

ACT conducted two performance evaluations of technologies for detecting and measuring harmful algae and harmful algae toxins subsequent to the 2017 workshop:

- a verification of Harmful Algae and Cyano-bacteria Multispectral Fluorometers in 2017, and
- a demonstration of Algal Toxins Detection Field Kits in 2018.

In the 2017 verification, ACT evaluated four commercially-available, *in situ* multi-excitation fluorometers from three vendors. Two of the vendors, BBE Moldaenke and Turner Designs had participated in the 2005 verification and submitted upgrades of their instruments for this verification. The evaluation focused on the capacity of these technologies to discriminate presence and abundance of cyanobacteria and harmful eukaryotic phytoplankton (diatoms, dinoflagellates, prymnesiophytes) within mixed natural communities. Laboratory tests were conducted using known algal cultures both individually and in various combinations along with add-in matrix challenges for turbidity and CDOM. Five different field testing applications were conducted including three continuous underway surface mapping cruises and two moored deployments.

Instrument performance was evaluated against extracted chlorophyll, extracted phycocyanin, and algal species classification at the functional group level on the basis of estimated biovolume contribution within each sample.

The ACT performance demonstration conducted in 2018 focused on several instruments and/or assays with the specific application of detecting HAB toxins in marine and freshwater systems, particularly those that are field-portable or field-deployable. Instruments evaluated in the demonstration included two of the test kits from one vendor, Phytoxigene™, which were available commercially at the time of testing but had not been verified for their utility and compatibility for field use. Two kits from Beacon Analytical Systems, one commercial and a beta version of the second; and a pre-commercial instrument from MBio Diagnostics also were evaluated in the demonstration. The demonstration quantified instrument/assay accuracy, precision, range/detection limits, and reliability against standard methods. Laboratory tests focused on quantifying accuracy, precision, dynamic range, and detection limit under controlled environments and considering matrix effects. The field tests were chosen to represent a broad range of environmental conditions and incorporated both freshwater and marine environments.

Outcomes - The BBE PhycoProbe evaluated in the 2017 fluorometer verification is being used globally, including by Environment Canada; by the Huayan Hong Kong & China Water Co., Ltd, Suzhou, China to monitor Chinese water systems (Moldaenke et al, 2019) , and by EPA in Gulf Breeze, FL (www.fedconnect.net/FedConnect/default.aspx?ReturnUrl=%2ffedconnect%2f%3fdoc%3d68he0b20q0211%26agency%3depa&doc=68he0b20q0211&agency=epa). The Turner Designs CyanoFluor and PhytoFind are used by numerous federal (EPA, USGS) and state agencies in water quality surveys across the US. The JFE Advantech Co. multi-excitation fluorometer, originally designed to discriminate between phytoplankton species present within a population, was redirected for the measurement of phytoplankton chlorophyll-a fluorescence quantum yield (FQY) in a number of studies in the Southern Atlantic Ocean by South African scientists (Griffith, et al., 2018).

Subsequent to the algal toxin detection demonstration, the Beacon Analytical Systems kit was used in a study to optimize water treatment operations to reduce cyanotoxin risks in one of the largest water treatment plants in Sweden (Li et al, 2019). Although the MBio Diagnostic's system was in a pre-commercial state of development at the time of testing, the company had a Phase I SBIR award from the National Institute of Food and Agriculture (NIFA), part of the USDA, for developing a platform for algal toxin detection. In 2019, the company received a Phase II SBIR award to develop three assays to measure saxitoxin, domoic acid, and okadaic acid and an award from the NOAA Monitoring and Event Response for Harmful Algal Blooms program (MERHAB), to monitor microcystin and cylindrospermopsin in Lake Erie. This project deployed the company's HAB toxin system to twelve different sites, leading to a network of data that can be used for HAB forecasting models. The first-generation of this Toxin System became available for commercial sale in 2018 (Bickman et al., 2018).

4.1.4. ACT Theme: Hypoxia

Background - In ocean and freshwater environments, the term "hypoxia" refers to low or depleted oxygen in a water body (NOAA, 2022). Water masses can become undersaturated with oxygen when natural processes alone or in combination with anthropogenic processes produce enough organic carbon that is aerobically decomposed faster than the rate of oxygen reaeration. (Rabelais et al, 2010). Hypoxic water masses have oxygen concentrations of less than 2-3 mg/L (EPA, 2022). Efforts to monitor and mitigate hypoxia are reliant on accurate and reliable *in situ* dissolved oxygen (DO) sensors. .

The measurement of DO over time provides the evidence for the increase or worsening of hypoxia in coastal waters worldwide, including the northern Gulf of Mexico influenced by the Mississippi River discharge and in the Chesapeake Bay. DO measurements also provide data to develop standards for water quality criteria that are protective of designated uses, assessment of compliance to the subsequent water quality criteria, standards for development of TMDLs (total maximum daily loads that maintain water quality standards), and information to develop mitigation measures to improve oxygen conditions.

The dissolved oxygen sensors market is expected to reach US$ 786.4 million by 2026 and is projected to expand at a CAGR of 7.36% from 2018 to 2026 (Transparency Market Research, 2019). The market is expected to be influenced by a range of factors such as need for accurate and reliable measurements, need for minimized installation and maintenance time, and growing importance of environmental monitoring.

Activities - The first ACT Technology Evaluation in 2004 and two of the first ACT Technology Workshops (2004 and 2006), focused on *in situ* instrumentation to measure DO. ACT resources were put towards these efforts because of: (a) broad and considerable stakeholder (researchers, resource managers, technology developers/manufacturers, etc.) interest in reliable, accurate and cost effective measures of *in situ* DO, (b) IOOS selection of DO as a priority water quality variable, and (c) the emergence of new optical dissolved oxygen sensors.

The 2004 DO sensor verification preceded an industry wide shift toward the adoption of a range of optical DO sensor formats. In the decade following this verification, there were significant advancements in this class of instrumentation, and the need for accurate and reliable spatially and temporally intensive measurements of DO in fresh, coastal and ocean waters around the world remained a high priority. ACT conducted a second verification of these "next generation" *in situ* DO sensors during 2015-2016.

As a result, a solid knowledge of sensor characteristics and best practices has emerged. for users that need information and guidance on how to use oxygen optodes in an optimal way.

Performance Verification of Dissolved Oxygen (DO) Sensors, 2004 **-** The 2004 DO sensor verification focused on deployments on remote platforms in relatively shallow water (< 10 meters depth). The instrument performance parameters evaluated were accuracy, reliability, precision, instrument drift/calibration life, and operating life were the most important parameters guiding instrument selection decisions.

A total of eight sensors from four participating companies were evaluated during this verification, four with the manufacturers' biofouling prevention system and four without. Two of the companies had electrochemical or Clark-type DO sensors. Yellow Spring Instruments' (YSI) electrochemical sensor was polarographic; Greenspan offered a galvanic type of electrochemical DO sensor. The other two companies' sensors, In-Situ and Aanderaa, were optical DO sensors, known as fluorescent sensors.

There were a total of 56 distinct instrument evaluations of the key performance factors. Laboratory tests were conducted to evaluate accuracy, precision, instrument drift, and reliability. Field tests were conducted at seven ACT Partner sites. Separate verification reports for each instrument were posted on the ACT website.

The verification found that many of the instruments provided very accurate values in the laboratory tests. ACT did not report differences between the electrochemical and optical sensor types. In the field tests, biofouling was a major factor in the differences found between the instruments' values and the values of reference samples (Figures 11 and 12). For example, the YSI ED Rapid Pulse™ Dissolved Oxygen Sensor incorporated as part of the EDS sonde with a wiper kit resisted fouling in Bayboro, FL for 2.5 weeks, whereas the standard sonde without the antifouling device showed effects of fouling in two days.

Figure 11. Biofouling of dissolved oxygen sensors after 26-days deployment in Chesapeake Bay in September 2012 (a) predeployment, (b) with biofouling prevention, (c) without biofouling prevention system.

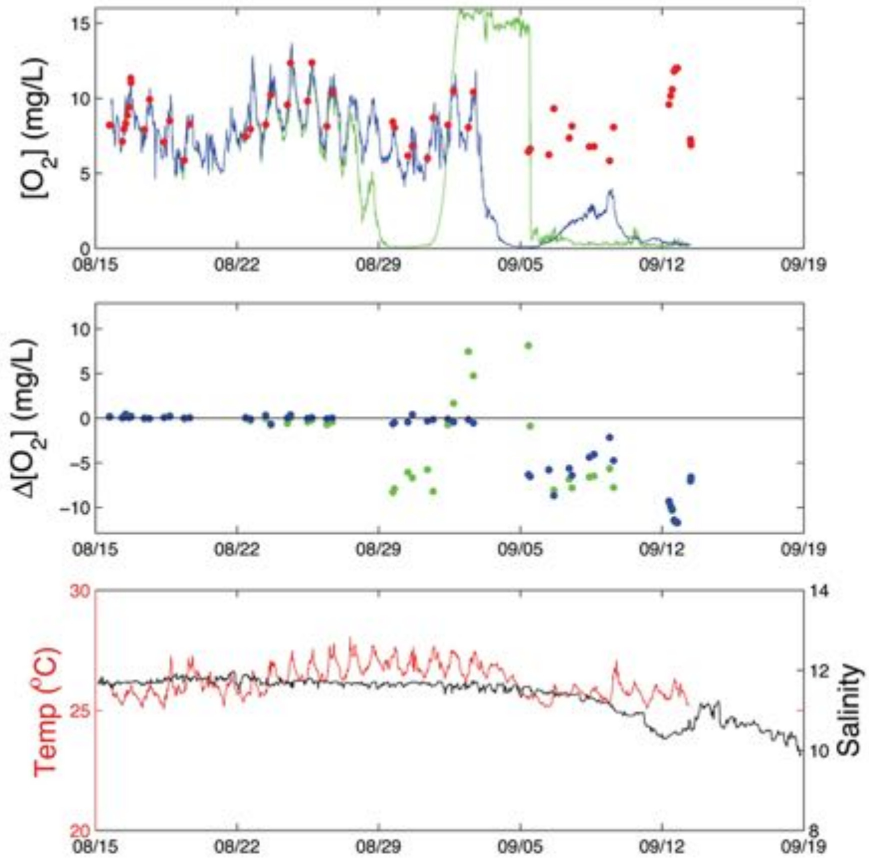

Figure 12. Example of instrument drift and degradation of sensor due to biofouling.

Following the 2004 verification, on May 18, 2012, the In-Situ RDO became the first optical DO method to receive nationwide, Tier 3 EPA approval for Biochemical Oxygen Demand (BOD), Carbonaceous Biochemical Oxygen Demand (CBOD), and Dissolved Oxygen (DO) under the Clean Water Act. The In-Situ RDO methods are included in the final Methods Update Rule (http://water.epa.gov/scitech/methods/cwa/update.index.cfm). National Pollution Discharge and Elimination System (NPDES) permit holders were able to begin monitoring with In-Situ RDO methods.

Aanderaa released its model MK1 3830/3930/3835 optical-based oxygen sensors in 2002. Subsequent to the ACT evaluation of its MK1 models in 2004, Aanderaa introduced its next generation MKII Optode models in 2008. The oxygen Optode 3835 was replaced by the 4835 model, and the oxygen Optode 3830/3930C was replaced by 4330/4831 optodes. Improvements to the MKII Optodes were made based in part on performance data of the ACT evaluation of the MK1 optode. The new sensors have improved electronics, optics, temperature compensation, formulas to calculate absolute oxygen, and can be individually multipoint calibrated to enhance accuracy. According to Aanderaa, “several thousands of our optodes are in use around the world and *in situ* applications of the sensor have ranged from streams to deep sea, from fish farms to waste water, and from polar ice areas to hydrothermal vents”.

Performance Verification of Dissolved Oxygen (DO) Sensors, 2015-2016 - Some of the same vendors who participated in this verification test participated in the 2004 DO sensor verification test as well, although the evaluated technologies were not the same . The verification included several months of laboratory testing along with three field deployments covering freshwater, estuarine, and oceanic environments. Laboratory tests evaluated sensor accuracy, precision, response time, and stability at three fixed salinity levels (0, 10, 35) at each of three fixed temperatures (4, 15, 30 ^{o}C). Three field-mooring tests were conducted to examine the ability of test instruments to consistently track natural changes in DO over extended deployments of 12-16 weeks at three sites with varying salinity ranges: Lake Superior, MI (under ice); Chesapeake Bay, MD; and Kaneohe Bay, HI. Several of the sensors were evaluated in profiling field tests in the Great Lakes at two separate locations in order to experience both normoxic and hypoxic hypolimnion.

Figure 13 . DO sensor deployments in Lake Superior (January 2015) and Chesapeake Bay (June 2015).

The verification found the majority of the instruments tested showed good linearity over all three salinity ranges including freshwater, brackish water, and oceanic water. Good agreement between instrument and reference measurements was observed over a wide range of DO conditions. Biofouling remained a significant problem in the long-term deployment at the Chesapeake Bay site.

Figure 14. An example of a test instrument prior to deployment and the test instrument after the Chesapeake Bay field deployment to indicate potential impact of biofouling.

Participating vendors have continued to improve their instrumentation. For example, in 2004 shortly after participating in the first ACT DO sensor verification, In-Situ Inc. released the Troll 9000 Rugged DO (RDO) sensor, which was tested in this verification. In-Situ now offers several anti-fouling systems for all its sondes. YSI also participated in the 2004 verification. The YSI EXO sonde tested in this second verification offered biofouling protection with copper-alloy components and anti-fouling wipers.

Outcomes - As a result of ACT's DO sensor verifications, a solid knowledge of sensor characteristics and best practices has emerged for users that need information and guidance for operation and calibration of oxygen optical sensors for optimum performance. Sensors are becoming smaller, smarter, and cheaper. Advanced deployment platforms now exist with state-of-the-art power and communications capabilities. However, as shown in the ACT 2004 DO sensor verification, biofouling was and still remains a significant factor affecting operation, maintenance, and data quality. ACT estimated that maintenance costs of sensors, due to biofouling not just limited to DO sensors, consume 50% of operational budgets. As a result, vendors have invested in incorporating a number of anti-fouling features into their sondes, and sensors are now able to maintain performance without cleaning or recalibration over extended, long-term deployments in aggressive fouling environments.

4.2. Response to Environmental Emergencies and Agency Needs

In addition to its long-term, multiple activities on environmental challenges such as climate change and nutrient pollution, ACT also maintained a flexible capability to respond to environmental emergencies and requests from NOAA and other federal agencies to assist in evaluating technological solutions to respond to these issues. These special activities included:

- development of test and evaluation protocols with IOOS, NDBC, and USACE in support of A National Operational Wave Observation Plan*;*
- a verification of hydrocarbon sensors following the Deepwater Horizon well blowout in the Gulf of Mexico;
- a verification of shipboard compliance-monitoring devices for rapid analysis of ballast water from ships for non-indigenous species
- a series of two virtual workshops (due to the COVID-19 pandemic) in partnership with the Marine Biodiversity Observation Network (MBON) with IOOS on *Envisioning the Future of eDNA Sampling and Sample Processing*.

In 2009, ACT supported IOOS, NDBC and USACE in developing a plan for a comprehensive, high quality surface wave monitoring network for the U.S. entitled A National Operational Wave Observation Plan. In 2010, ACT took the first step in implementing the Plan by developing the protocols for such a technology testing and evaluation effort.

ACT initiated a performance verification of *in situ* hydrocarbon sensors focused on both moored and profiling applications in May 2011. Six technologies were evaluated. The laboratory and tank test experiments showed that the fluorometric sensors were capable of detecting oil, but the presence of CDOM, turbidity and algae-derived substances substantially affected the detection capabilities. Future evaluations of some of the verified sensors showed similar results (Pärt, et al. 2021). Autonomous sensors may work well in detecting hydrocarbons in the marine environment. The main uncertainty is how the sensors' calibration and specificity to oil, and the measurement depth, affects oil detection.

In response to a request from the U. S. Maritime Administration (MARAD), Office of Environmental Activities and the U.S. Coast Guard (USCG) Research and Development Center

(RDC), ACT partnered with the Naval Research Laboratory (NRL), the Great Ships Initiative (GSI), and the Smithsonian Environmental Research Center (SERC) to conduct a verification of available tools for shipboard monitoring of aquatic invasive species introductions in ballast water discharged from ships during July to September 2015 and March to July 2016. Ships must meet standards limiting the concentrations of living organisms in ballast water discharged in US waters. Monitoring devices to confirm compliance with these standards have largely—although not exclusively (e.g., van Slooten et al. 2015)—used variable fluorescence fluorometry. This approach targets phototrophic microalgae, and it determines the relative abundance and physiological status of microalgae in a sample (Casas-Monroy et al. 2016; Bradie et al., 2017). Five of the instruments were capable of discrete sample analysis and designed to be carried by hand aboard a ship. These testing apparatuses employ multiple turnover pulse amplitude modulated (PAM) technology to measure variable fluorescence. One flow-through device uses single turnover active fluorometry (STAF) and is engineered to be installed aboard a ship and integrated into the piping system. The six devices were evaluated in a series of laboratory and field tests at three contrasting coastal locations.

One documented outcome of the evaluation was that following the evaluation Saudi Aramco, the world's largest oil producer, approved the use of the Turner Designs' Ballast-Check 2 Handheld PAM Fluorometer to show compliance with the IMO Ballast Water Management 2004 convention. all ships calling at its ports and terminals (Maritime Executive, 2017).

ACT and IOOS, in partnership with the Marine Biodiversity Observing Network (MBON) conducted two virtual workshops on *Envisioning the Future of eDNA Sampling and Sample Processing*, to discuss current barriers and challenges associated with different aspects of environmental or eDNA sample collection and processing. The workshop's recommendations will inform IOOS and MBON, on implementation of NOAA 'omics strategy, including coordination around data management solutions, development of new technologies to lower the cost of eDNA sampling, and expand applicability to new environments such as the deep ocean (NOAA 2020).

5. OUTPUTS, OUTCOMES, AND LESSONS LEARNED

In measuring performance of ACT's program activities, "output" measures are distinguished from "outcomes." Outputs tell the story of what was produced e.g., the number of technologies evaluated and testing protocols developed. However, output measures do not address the value or impact of these services and activities for ACT's clients.

ACT has made every effort to quantify potential outcomes from its activities and from applying the technology. However, outcomes regarding the further advancement or use of the technologies were not produced during the verification tests themselves or through sustained follow-up efforts. For example, vendors of ACT-verified technologies are not required to track their sales or report the effects of ACT verification to ACT. Where insufficient data were available to quantify an outcome, the case studies present information about that outcome and describe its potential significance qualitatively.

5.1. Outputs

From its inception, ACT:

- Organized a networked, co-laboratory, consisting of a coordinating headquarters unit and regionally distributed and geographically diverse partner coastal research institutions, with mechanisms for extensive stakeholder participation.
- Established an internationally recognized, rigorous and quality assured, third-party testing infrastructure for evaluating existing, new and developing sensor and sensor platform technologies.
- Conducted 421 verifications and demonstrations of marine sensors in multiple diverse environments. ACT tested 11 instrument classes (dissolved oxygen and chlorophyll a fluorometry were done twice) in controlled laboratory conditions and in hand-held, moored, depth profiling, and surface mapping applications in field sites including Kaneohe Bay, HI, Resurrection Bay, AK, Monterey Bay, CA, Chesapeake Bay, MD, the Gulf of Maine, the Gulf of Mexico, and the Great Lakes.
- Accepted thirty-four companies to participate in ACT verifications. The majority of these companies are small- to medium-sized enterprises (SMEs); 14 companies participated multiple times (1 company participated in 10 verifications).
- Created an innovative technical workshop format in which participants from all relevant sectors, i.e., R&D, manufacturing, and "operational" coastal management, convened to describe the state of technologies and to create roadmaps for future development. Forty-nine (49) technology workshops were conducted, involving over 1,500 participants from around the world.
- Focused technology evaluations and workshops on essential ocean variables (EOVs) for implementation within a global ocean observing system that will provide key information on global changes in marine resources and ecosystems in response to society's internationally agreed needs.
- Developed an online searchable database of environmental instrumentation as a resource for coastal managers, scientists and observing systems.

5.2. Outcomes

The outcomes presented below are ACT's estimates of potential outcomes from its activities and stakeholders using that information to applying the technology. The potential outcomes were not produced during the verification tests themselves or through sustained follow-up efforts. For example, vendors of ACT-verified technologies were not required to track their sales or report the effects of ACT verification to ACT. Instead, ACT presents potential outcomes by combining verified performance results with information from public sources (e.g., regulatory impact analyses, company websites, scientific research publications), reasonable assumptions, and logical extrapolations and describes the potential significance qualitatively.

These outcomes include:

Environment and Health

- Water utilities, such as the City of Toledo on the Maumee River and Lake Erie (both ACT test sites for HAB technology evaluations), recognized the importance of sensors and sensor research and made design structural modifications to new and existing facilities to better accommodate HAB sensor platforms.
- On May 18, 2012, the In-Situ RDO became the first optical dissolved oxygen (DO) method to receive nationwide, Tier 3 EPA approval for biochemical oxygen demand (BOD), carbonaceous biochemical oxygen demand (CBOD), and DO under the Clean Water Act. National Pollutant Discharge Elimination System (NPDES) permit holders were able to begin monitoring with In-Situ RDO methods.

Economic and Business

- Greater credibility and access to new markets for vendors based on verified performance information that differentiates new technologies from conventional approaches. ACT verifications helped to minimize the risks of associated with young technology.
- Provision of reliable information and performance benchmarks for innovative technologies with unique features in target markets with specific performance requirements, or where standards may not exist.
- Increased sales of verified technologies by vendors.
- Examples include the following testimonials.

  "As a result of information derived from ACT's Towed Vehicle Workshop, Chelsea Instruments undertook an internal design and production review, with the aim of reducing costs. After working with several companies in China and Taiwan, Chelsea was able to reduce the cost of our towed vehicle fairing system, saving up to $30,000 per technology package for the end user."
  Richard Burt, Marketing Director, Chelsea Instruments, Ltd., UK

  "As a global supplier and leader in water quality sensing technologies, field portable and ruggedized instrumentation systems, and automated and autonomous data collection platforms, ACT has made a measurable and positive impact on our business. Specifically, ACT Workshops have helped focus and steer our marketing, and research & development initiatives. ACT Technology Evaluations have provided us with valuable information and feedback about the state of our own technology, allowing us to make changes, modifications, and adjustments to our products, designs, and future research and development activities. ACT has helped accelerate the transition of our newer technologies toward a more effective and wide scale, operational use."
  Kevin McClurg, Sales and Business Development Manager, XYLEM/YSI Inc.

  "WET Labs entered its products into two recent ACT evaluations in 2005 and 2006. Within the past year, I can recall at least three separate NOAA groups' remarks on

the resultant ACT reports when considering purchase of our company's products. Moreover, sales of our related product lines have grown by well over 50% during the past year – in part, attesting to the adoption of these tools by the water monitoring community."
Casey Moore, President, WET Labs, Inc.

"I am very impressed with their detailed preparation for the study. "They fully defined all sampling protocols and cell-counting methods. They're looking at several different natural waters as well as algal monocultures with known interferences. They have an array of forms in place so data will be collected consistently across the three sites. We are very excited to be part of this validation and anxious to see the results."
Pam Mayerfeld, Vice President of Marketing and Sales, Turner Designs

Regulatory

- Verified performance data supported evidence-based regulatory objectives, such as EPA's regulations on total maximum daily loads (TMDLs) to maintain water quality standards,.
- Expedited permitting and regulatory approvals for implementation and use of verified technology.
- Agencies have been moving toward allowing the use of performance-based testing methods to replace some of the rigid, highly prescriptive testing methods in regulations. Widespread adoption of performance-based testing methods would remove some barriers to innovation.
- ACT advanced technologies for the measurement of two keystone variables for monitoring ocean acidification. CO_2 and pH levels in the open ocean and coastal waters will become paramount in assessing impacts of ocean acidification and potential future regulatory criteria, both nationally and internationally.
- Examples include the following testimonial.

"A direct result of the ACT Workshop on Underwater Passive Acoustic Monitoring of Remote Regions was the formation of partnerships between academics, managers, and military personnel to use an emergent technology to solve a priority marine conservation issue, and the enforcement of fisheries regulations in remote areas within the newly formed Papahanamokuakea Northwestern Hawaiian Islands Marine National Monument."
Melissa Bos, Main Hawaiian Islands Seascape Strategy Facilitator Consultant to Conservation International

Technology Acceptance and Use

- ACT's unbiased information on technology performance is an important factor for coastal managers and ocean industries in selecting new technologies.
- ACT's development of well- and broadly- accepted protocols for technology testing has advanced efforts to standardize testing protocols across programs.
- Examples include the following testimonials.

"As the lead agency for monitoring and assessing the health of the Chesapeake Bay, Maryland DNR is continually evaluating new monitoring and assessment technologies. ACT has played a key role in this process, as DNR does not have the resources to evaluate the myriad of new monitoring technologies and instrument manufacturers to select the most accurate and reliable sensors. Participation in ACT activities has saved DNR countless dollars and hundreds of hours of staff time, provided the justification for purchasing and deploying specific instruments, and, ultimately, provided us with the means to better understand the status of the Bay."
Bruce Michael, Director of Resource Assessment Service, Maryland Department of Natural Resources

"We use the ACT Technology Evaluation reports, and consult with the regional ACT Partner, when purchasing sensors for PacIOOS ."
Chris Ostrander, Director of the Pacific Island Ocean Observing System (PacIOOS), University of Hawaii

Scientific Advancement

- ACT stakeholders agreed that ACT workshops created an excellent foundation for establishing "roadmaps" for transition and adoption of new technologies. ACT workshops provided unique opportunities for peer-to-peer, cross-sector, and multi-disciplinary networking; and contributed to knowledge synthesis on existing capabilities and consensus-building on next steps to move technologies forward.
- Results of ACT technology evaluations provided important insight to the broader community on how to interpret data provided by *in situ* instrumentation and thus how to appropriately measure/ estimate various environmental parameters (e.g., Luther et al., 2008; Boss et al., 2009; Tamburri et al., 2011) .
- ACT verifications provide assurance that basic science understanding, forecasting, and management decisions are based on accurate, precise, and comparable observing data, while minimizing the risk of artifacts and problems associated with young technology.
- Ocean technology companies agreed that ACT evaluations contributed to improvements in their technologies and improve acceptance in the market.
- ACT workshops helped to create marine technology R&D funding opportunities through other organizations, e.g., Small Business Innovation Research program (SBIR), National Oceanographic Partnership Program (NOPP).
- ACT Technology Test Protocols serve as a basis for Ocean Sensor Technologies best practices. The Ocean Best Practices Repository (OBPS-R) lists 81 ACT documents with links to the full reports (https://repository.oceanbestpractices.org). The OBPS-R is an open access, permanent, digital repository of community best practices in ocean-related sciences and applications maintained by the International Oceanographic Data and Information Exchange (IODE) of the UNESCO-IOC as an IOC (IODE, GOOS) coordinated activity.

5.3. Lessons Learned

- Independent third party testing is not a new idea. However, for new technologies coming onto the market, it should be considered a prerequisite.
- Stakeholder interactions play a key role in true integration of innovative technologies into existing monitoring systems, where the societal and human dimension is considered together with the scientific one.
- Coastal managers are risk averse and tend to use technologies that have been time-tested and proved to be reliable. Vendor-generated data on technology performance is viewed with skepticism. Reports from well-established research centers such as the ACT Partner institutions, instills some confidence in the information.
- It is critical that vendors participate in test protocols development, and companies must be able to provide a representative for direct face to face training of the technical personnel conducting the evaluation and that these staff have experience with programming and using specific instruments prior to any testing.
- Instruments may malfunction in the field at any time during a deployment despite appearing to be operating correctly upon initial deployment. Data transmission and monitoring is critical for long-term deployments.
- There is a clear difference in instrument performance between laboratory and field, and instrument performance in the field usually depends on type of application (e.g., moored, vertical profiling, surface mapping), the environment (rivers, lakes, estuaries, coral reefs, fjords and open ocean), and nature and severity of biofouling. Instrument performance evaluation should be conducted at multiple sites and environmental conditions.
- Sampling techniques and locations can result in highly variable results. Standard operating procedures for collecting and processing of reference samples should be followed or developed when assessing technology performance.
- While anti-fouling approaches are available (such as coatings, copper screens, and mechanical wipers), sensor deployments of more than two to three weeks were typically not possible during spring and summer months in highly productive coastal waters (Figure 11).
- Many instruments with long histories of use for measuring basic physical or chemical parameters may not always perform to manufacture specifications in the field, and users should be cautioned of their limitations. The ACT technology verification of *in situ* salinity sensors (conductivity + temperature) found that many instruments provide very accurate and reliable values. However, in some cases, consistent offsets were found between instruments collected and laboratory analyzed values (Figure 12). Power management and sampling / response-time also are often issues for instruments deployed in coastal waters with rapidly changing parameters. Thus, IV&V of instruments under diverse conditions is critical.
- Outreach, i.e., providing “awareness” information alone regarding environmental technology innovations is inadequate with respect to encouraging adoption. Likewise, verification alone will not move better, cheaper, faster technologies into the marketplace. Barriers still exist regarding the acceptance of verified data by users. Strategies are needed for getting the information directly to these federal and state government and industry users in ways that will increase their comfort level in more readily accepting the verified data
- Interpersonal channels are more effective in forming and changing attitudes toward a new idea, and thus in influencing the decision to adopt or reject an innovation. Most individuals

evaluate an innovation through communications with near-peers who have adopted the innovation. Diffusion "takes off" once interpersonal networks become active in spreading subjective evaluations of the innovation from peer to peer. There is an interaction effect, i.e., adopters influence those in the community who have not yet adopted.

6. CONCLUDING REMARKS

Leveraging technologies for a healthy environment will require ongoing collaboration between those who create the tools and those who understand the systemic environmental challenges. Acting as matchmakers between technology partners and problem-solvers, programs such as ACT can facilitate purposeful relationships and help to shape innovative new partnerships.

Technologies must not be considered holistic environmental solutions but simply tools to be leveraged to further environmental action. As communities, academic institutions, environmental non-governmental organizations and other stakeholders move along the technology journey, the funder community can bring more than grantmaking to the table. Skill training and capacity building are equally as valuable as the technical elements themselves.

The range of themes and examples of actions done by ACT explored in this report, while not exhaustive, provides pathways for developers and funders to consider as they evolve their own strategies and approaches to advance technological innovation in ocean observing systems. In addition to evaluating sensor performance with respect to data quality, another fundamental goal of an ACT evaluation is to address operational reliability and robustness of the sensors in terms of long-term consistency and dependability (e.g., withstand biofouling and corrosion). Not only are these keys to the success of operational ocean and coastal observing systems, but they are also the areas manufacturers have limited ability to conduct their own performance testing. The importance of reliable/dependable instruments for moored and autonomous observations translates into a great need *in situ* testing of the device at sea.

It is our hope that ACT is a first critical step in a larger conversation around the opportunities for deployment of emerging ocean technologies, as well as their social and environmental implications. In particular, the hope is that ACT, through is actions and the enumerable number of dedicated people who contributed to this effort over these past 20+ years, motivates future efforts to explore new and creative solutions to our largest global challenges.

7. REFERENCES

Anderson, D.M. 1989. Toxic algal blooms and red tides: a global perspective. In Red Tides: Biology, Environmental Science and Toxicology, eds. T. Okaichi, D.M. Anderson, T. Nemoto, pp. 11–16. New York: Elsevier.

American National Standard Institute/American Society for Quality Control. 1994. ANSI/ASQC E4-1994-Specifications and Guidelines for Quality Systems for Environmental Data Collection and Environmental Technology Programs.

Bickman S., K. Campbell, C. Elliott, C. Murphy, R. O'Kennedy, P. Papst, and M. J. Lochhead . 2018. An Innovative Portable Biosensor System for the Rapid Detection of Freshwater Cyanobacterial Algal Bloom Toxins. Environmental Science & Technology 52 (20). 11691–11698. doi: 10.1021/acs.est.8b02769

Boss, E., L. Taylor, S. Gilbert, K. Gundersen, N. Hawley, C. Janzen, T. Johengen, H. Purcell, C. Robertson, D. W. Schar, G. J. Smith, and M. N. Tamburri, 2009. Comparison of inherent optical properties as a surrogate for particulate matter concentration in coastal waters. Limnol. Oceanogr. Methods 7: 803-810.

Bradie J., K. Broeg, C. Gianoli, J. He, S. Heitmüller, A.L. Curto, A. Nakata, M. Rolke, L. Schillak, P. Stehouwer, J. Vanden Byllaardt, M. Veldhuis, N. Welschmeyer, L. Younan, A. Zaake, and S. Bailey. 2017. A shipboard comparison of analytic methods for ballast water compliance monitoring. Journal of Sea Research, DOI: 10.1016/j.seares.2017.01.006

Brown, E.G. 2016. Office of the Governor to the US Department of Commerce. https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=116284.

Casas-Monroy O., P.S. Chan, R.D. Linley, J. Vanden Byllaardt, J. Kydd, and S.A. Bailey. 2016. Comparison of three techniques to evaluate the number of viable phytoplankton cells in ballast water after ultraviolet irradiation treatment. Journal of Applied Phycology 28: 2821-2830

Griffith, D., E.L. Bone, and S. Bernard. 2018. Calibration of an in-water multi-excitation fluorometer for the measurement of phytoplankton chlorophyll-a fluorescence quantum yield. Environmental Science. doi:10.1364/oe.26.018863

Hallegraeff, G. 1993. A Review of Harmful Algal Blooms and Their Apparent Global Increase. Phycologia 32(2). DOI:10.2216/i0031-8884-32-2-79.1

International Organization for Standardization. 2016. ISO 14034:2016(en) Environmental management: Environmental technology verification (ETV). Geneva.

International Organization for Standardization. 2017. ISO 17025:2017(en) General requirements for the competence of testing and calibration laboratories. Geneva.

IOC-UNESCO, 2022. Multiple Ocean Stressors: A Scientific Summary for Policy Makers, (eds P.W. Boyd, S. Dupont and K. Isensee). Paris, France, UNESCO, 20pp. (IOC Information Series, 1404). DOI: http://dx.doi.org/10.25607/OBP-1724

Jewett, E.B., C.B. Lopez, Q. Dortch, S.M. Etheridge, and L. C. Backer. 2008. Harmful Algal Bloom Management and Response: Assessment and Plan. Interagency Working Group on Harmful Algal Blooms, Hypoxia and Human Health of the Joint Subcommittee on Ocean Science and Technology. Washington DC, 76 pp.

Kudela, R.M. 2015. Harmful Algal Blooms: A Scientific Summary for Policy Makers. IOC/UNESCO, Paris (IOC/INF-1320).Li, J. , K. Hagg, and K.M. Persson. 2019. The Impact of Lake Water Quality on the Performance of Mature Artificial Recharge Ponds. Water. Multidisciplinary Digital Publishing Institute (MDPI).

Lindquist, H.D.A., T. Faber, B. Patel, L. Boczek, J. Hoelle, K. Daniels, and G. Norris 2021. Experience using the winning sensor from the nutrient sensor challenge (using the WIZ for surface water). USEPA Office of Research and Development, National Risk Management Research Laboratory, Water Systems Division, Drinking Water Systems Branch.

Luther, M.E., S.A. Gilbert, and M.N. Tamburri, 2008. Status of sensors for physical oceanographic measurements. Mar. Tech. Soc. 42: 84-92.

National Oceanic and Atmospheric Administration. National Ocean Service. 2022. Hypoxia. https://oceanservice.noaa.gov/hazards/hypoxia/.

National Oceanography Centre. 2020. Oceanids Programme newsletter – December 2020. https://content.govdelivery.com/accounts/UKNOC/bulletins/2b01d82.

Pärt S., H. Kankaanpaa, J-V. Bjorkqcist, and R. Uiboupin. 2021 Oil Spill Detection Using Fluorometric Sensors: Laboratory Validation and Implementation to a FerryBox and a Moored SmartBuoy. Front. Mar. Sci. 30 November 2021. https://doi.org/10.3389/fmars.2021.778136.

Pellerin, B. A., B. A. Stauffer, D. A. Young, D. J. Sullivan, S. B. Bricker, M. R. Walbridge, G. A. Clyde, Jr., and D. M. Shaw. 2016. Emerging Tools for Continuous Nutrient Monitoring Networks: Sensors Advancing Science and Water Resources Protection. Journal of the American Water Resources Association (JAWRA) 52(4): 993-1008. DOI: 10.1111/1752-1688.12386.

Rabalais, N.N., R. J. D´ıaz, L. A. Levin, R. E. Turner, D. Gilbert, and J. Zhang. 2010. Dynamics and distribution of natural and human-caused hypoxia. Biogeosciences, 7: 585–619.

Tamburri, M.N., 2011. ACT: Supporting innovation for better ocean prediction and management. Sea Technology, 52:29-30.

Tillman, E.F., 2017. Evaluation of the Eureka Manta2 Water-Quality Multiprobe Sonde: U.S. Geological Survey Open-File Report 2017–1118, 37 p., https://doi.org/10.3133/ofr20171118.

Transparency Market Research. 2009. Dissolved Oxygen Sensors Market - Global Industry Analysis, Size, Share, Growth, Trends, and Forecast 2018 – 2026. 225pp.

United States Environmental Protection Agency (U.S. EPA). 2000. Guidance on Technical Audits and Related Assessments for Environmental Data Operations (QA/G-7).

United States Environmental Protection Agency (U.S. EPA). 2002. Guidance on Environmental Data Verification and Data Validation (QA/G-8).

United States Environmental Protection Agency (U.S. EPA), Mississippi River/Gulf of Mexico Hypoxia Task Force. 2022. Hypoxia 101. https://www.epa.gov/ms-htf/hypoxia-101.

APPENDIX 1. ACT ACTIVITIES BY THEME

ISSUE	SENSOR EVALUATION	WORKSHOP
Ocean Acidification and Climate Variability	• *In situ* pH (2012 -2014) • pCO_2 (2009)	• Science Assessment of Chesapeake Bay Acidification: Toward a Research and Monitoring Strategy (2014) • Measurement of Dissolved Organic Carbon Speciation in Natural Waters (2005)
Harmful Algal Blooms (HAB)	• Chlorophyll Fluorometers (2005) • Multi-spectral Fluorometers (2017) • Algal Toxins (2018)	• Sensors for Monitoring Harmful Algae, Cyanobacteria and Their Toxins (2017) • Technologies and Methodologies for Detecting HABs and Their Toxins (2008) • Application of in situ Fluorometers in Nearshore Waters (2005) • Biosensors for Harmful Algal Blooms (2002)
Aquatic Invasive Species, Ballast Water Treatment, and Biofouling	• Variable fluorescence fluorometers for use in compliance monitoring of ballast water discharge (2015) • Total residual oxidants (2019)	• Biofouling Prevention Technologies for Coastal Sensor/Sensor Platforms (2003)
Hypoxia and Nutrients	• Dissolved oxygen sensors (2004 and 2015-2016) • Nutrients (2007 and 2015 – 2016)	• Proceedings of Nutrient Sensor Challenge Workshop (2014) • In Situ Nutrient Sensors II (2006) • Dissolved Oxygen Probes (2006) • State of Technology in the Development and Application of Dissolved Oxygen Systems (2004) • State of Technology in the Development and Application of Nutrient Sensors (2003)

Water Quality	• Turbidity (2006) • Salinity (2008)	• Sampling the Aquatic Environment: Technologies for Sample Concentration, Remote Sampling and Sample Return (2011) • State of Technology for In Situ Measures of Salinity Using Conductivity Temperature Sensors (2007) • Monitoring for Organic Chemical Loading (2006) • Genetic Sensors for Environmental Water Quality (2005) • Measures of Turbidity in Coastal Waters (2005) • Trace Metal Sensors for Coastal Monitoring (2005) • Rapid Microbial Indicator Methods (2003)
Oil Pollution	• Hydrocarbon and CDOM sensors	• Hydrocarbon Sensors for Oil Spill Response (2008)

Observing Platforms and Infrastructure		• Practical Uses of Drones to Address Management Problems in Coastal Zones (2018) • National Coastal Ecosystem Moorings (2018) • Autonomous Surface Vehicles (2015) Biological Platforms for Environmental Sensors (2007) • Towed Vehicles as Platforms for Mapping Coastal Features and Processes (2007) • Sensor Inter-operability (2006) • Integrated Sensor Systems for Vessels of Opportunity (2006) Seabed Sensor Technology (2006) • Application of Drifting Buoy Technologies for Coastal Watershed and Ecosystem Monitoring (2005) • Application of Mini-ROV Systems for Coastal and Estuarine Monitoring (2004) • Mobile Sensor Platforms: Management Applications for AUVs and Gliders in the Nearshore Environment (2004) • Developing Technologies for Environmental Micro-Chemical Sensors (2004) • Data Telemetry Technologies for Coastal Ocean Observation (2003)
Coastal Ocean Physical Processes		• Wave Measurement Systems Evaluation Protocol (2012) • Wave Sensor Technologies (2007) Current Meters (2005) • Radar Technologies for Surface Current Mapping (2004)

Habitat and Resource Monitoring		• Envisioning the Future of eDNA Sampling and Sample Processing (2020) • Coastal Hyperspectral Algorithms (2020) • Hyperspectral Imaging of Coastal Waters (2018) • Passive Acoustic Hydrophones (2007) • Optical Remote Sensing of Coastal Habitats (2006) • Acoustic Remote Sensing Technologies for Coastal Imaging and Resource Assessment (2004) • State of Technology and Application of Optical Particle Counters (2004) • Developing Acoustic Methods for Surveying Groundfish (2003)
Other		• Application of Medical Sensor Technologies to Environmental Monitoring (2005) • Application of Sensor Technology to Assess Groundwater-Surface Water Interactions in the Coastal Zone (2005)

APPENDIX 2. ACT PEER-REVIEWED PUBLICATIONS

Boss, E., L. Taylor, S. Gilbert, K. Gundersen, N. Hawley, C. Janzen, T. Johengen, H. Purcell, C. Robertson, D. W. Schar, G. J. Smith, and M. N. Tamburri, 2009. Comparison of inherent optical properties as a surrogate for particulate matter concentration in coastal waters. Limnol. Oceanogr. Methods 7: 803-810.

Brasseur, L., M.N. Tamburri, and A. Plueddemann, 2009. "Sensor Needs and Readiness Levels for Ocean Observing: An Example from the Ocean Observatories Initiative (OOI) " in Proceedings of OceanObs'09: Sustained Ocean Observations and Information for Society (Vol. 2), Venice, Italy, 21-25 September 2009, Hall, J., Harrison D.E. & Stammer, D., Eds., ESA Publication WPP-306.

Bushnel, M., C. Waldmann, S. Seitz, E.N. Buckley, M.N Tamburri, E.S. Heslop, J.Hermes, and A. Lara-Lopez, 2019. Quality Assurance of Oceanographic Observations: Standards and Guidance Adopted by an International Partnership. Frontiers Mar. Sci. 6:706-717.

Dierssen H.M, S Ackleson, K Joyce, E Hestir, A Castagna, S Lavender, MA McManus. 2021. Living up to the Hype of Hyperspectral Aquatic Remote Sensing: Science, Resources and Outlook. Frontiers in Environmental Science. doi: 10.3389/fenvs.2021.649528

Drake, L.A., M.N. Tamburri, M.R. First, G.J. Smith, and T.H. Johengen, 2014. How many organisms are in ballast water discharge? A framework for validating and selecting compliance monitoring tools. Mar. Poll. Bull., 86:122-128.

First, M.R., L.A. Drake, V. Molina, C.S. Moser, S.H. Robbins-Wamsley, S.C. Riley, E.N. Buckley, A.A. Cangelosi, K.J. Carney, T.H. Johengen, H. Purcell, E.D. Reavie, G.J. Smith, and M.N. Tamburri, 2018. A test of the framework designed to evaluate compliance monitoring devices for ballast water discharge. Man. Biol. Invasions 9:505-513.

First, M.R., V. Molina, C.S. Moser, S.H. Robbins-Wamsley, S.C. Riley, C. S. Moser M. Tamburri, T.H. Johengen, H. Purcell, G.J. Smith, E.N. Buckley, and L.A. Drake, 2017. Performance evaluations of instrument for repaid, shipboard detectionof living microorganisms in ballast water. Man. Biol. Invasions 9:505-513.

Grand, M.M., G.S. Clinton-Bailey, A.D. Beaton, A.M. Schaap, T.H. Johengen, M.N. Tamburri, D.P. Connelly, M.C. Mowlem, and E.P. Achterberg, 2017. A Lab-On-Chip analyzer for long-term in situ monitoring at fixed observatories: Optimization and performance evaluation in estuarine and oligotrophic coastal waters. Front. Mar. Sci., 4:255-271.

Luther, M.E., S.A. Gilbert, and M.N. Tamburri, 2008. Status of sensors for physical oceanographic measurements. Mar. Tech. Soc. 42: 84-92.

Luther, M.E., G. Meadows, E. Buckley, S.A. Gilbert, H. Purcell, and M.N. Tamburri, 2013. Verification of wave measurement systems. Mar. Tech. Soc., 47:281-289.

McManus, MA, E Hochberg. 2019. Teams Invited to Test Coastal Hyperspectral Imaging Algorithms. EOS. 100, https://doi.org/10.1029

Pearlman, J., M. Bushnell, P.L Buttigieg, Coppola, L., Pearlman, F., Barbier, M., Simpson, P., Munoz, C., Karstensen, J., Muller-Karger, F., Pissiersens, P., Hermes, J., Heslop, E., Jenkyns, R., Achterberg, E., Bittig, H., Bourles, B., Buck, J., Cusack, C., Delory, E., Garello, R., Hartman, S., Heitsenrether, R., Lara Lopez, A., Leadbetter, A., Manzella, G., Maso, J., McCurdy, A., Moussat, E., Petihakis, G., Pinardi, N., Pouliquen, S., Przeslawski, R., Roden, N., Silke, J., Tamburri, M.N., Tanhua, T., Thomas, J., Waldmann, C., Whoriskey, F., Bensi M., Bozzano R., Blandin J., Cano D., Cardin V., Charcos Llorens M., Cianca A., Giovanetti G., Lanteri N., Ntoumas M., Pensieri S., Stasch C., Toma M., Tengberg A., 2019. Evolving and sustaining ocean best practices and standards for the next decade. Frontiers Mar. Sci. 6:277-296.

Pellerin, B A., B. A. Stauffer, D. A. Young, D. J. Sullivan, S.B. Bricker, M. R. Walbridge, Stauffer, B.A., T.H. Johengen, G.J. Smith, A.J. VanderWoude, T. Davis, R. Kudela, and M.N. Tamburri, 2019. Considerations in Harmful Algal Bloom Research and Monitoring: Perspectives From a Consensus-Building Workshop and Technology Testing. Frontiers Mar. Sci. 6:399-416.

Stauffer, B.A., T.H. Johengen, G.J. Smith, A.J. VanderWoude, T. Davis, R. Kudela, and M.N. Tamburri, 2019. Considerations in Harmful Algal Bloom Research and Monitoring: Perspectives From a Consensus-Building Workshop and Technology Testing. *Frontiers Mar. Sci.* 6:399-416.

Tamburri, M.N., M.J. Atkinson, E.N. Buckley, T.H Johengen, M.E. Luther, G.A. Meadows, and G.J. Smith, 2012. Technologies to meet IOOS and societal needs. Community White Paper, IOOS Summit Proceedings, Interagency Ocean Observing Committee, 90:1-5.

Tamburri, M.N., T.M. Johengen, M.J. Atkinson, D.W.H. Schar, C.Y. Robertson, H. Purcell, G.J. Smith, A. Pinchuk, and E.N. Buckley, 2011. Alliance for Coastal Technologies: Advancing moored pCO2 instrumentation in coastal waters. Mar. Tech. Soc., 45:43-51.

Tamburri, M.N., 2011. ACT: Supporting innovation for better ocean prediction and management. Sea Technology, 52:29-30.

Tamburri, M.N., Bailey, S.A., Everett, R.A., First, M.R., Gollasch, S., Outinen, O., and Drake, L.A., 2020. Protocol for the Verification of Ballast Water Compliance Monitoring Devices. ICES Tech. Mar. Environ. Sci. 63:1-13.

Waldmann, C., M.N. Tamburri, R. Prien, and P. Fietzek, 2010. Assessment of sensor performance. Ocean Sci. 6:1687-1716.

Zimmer-Faust, A.G., R. Ambrose, and M.N. Tamburri, 2014. Evaluation of approaches to quantifying total residual oxidants for use in monitoring ballast water management systems. Water Sci. & Tech., 70:1585-1598.

APPENDIX 3. ACKNOWLEDGEMENTS

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- Dr. Lisa Drake, Section Head of Code 6137, Marine Biological Engineering
- Dr. Matthew First, Senior Scientist
- Stephanie H. Robbins-Wamsley, Senior Scientist
- Scott Riley, Senior Scientist
- Dr. Vanessa Molina, Senior Scientist

OTHER FEDERAL
- Dr. Denise Shaw, Senior Scientist, USEPA
- Dr. Carolyn Junemann, Environmental Protection Specialist, MARAD
- Dr. Gail Roderick, Research Scientist, USCG

OTHER
- Dr. Earle Buckley. NOAA/CSC ACT Program Officer (1998-2002), ACT Quality Manager (2003- 2021)
- Curt Dove, McLean Research Corp (1997 – 1999)
- Andrew Gembara, G&H International Services, LLC (1997 – 1999)
- Robert Greenberg. G&H International Services, LLC (1997 – 1999)


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