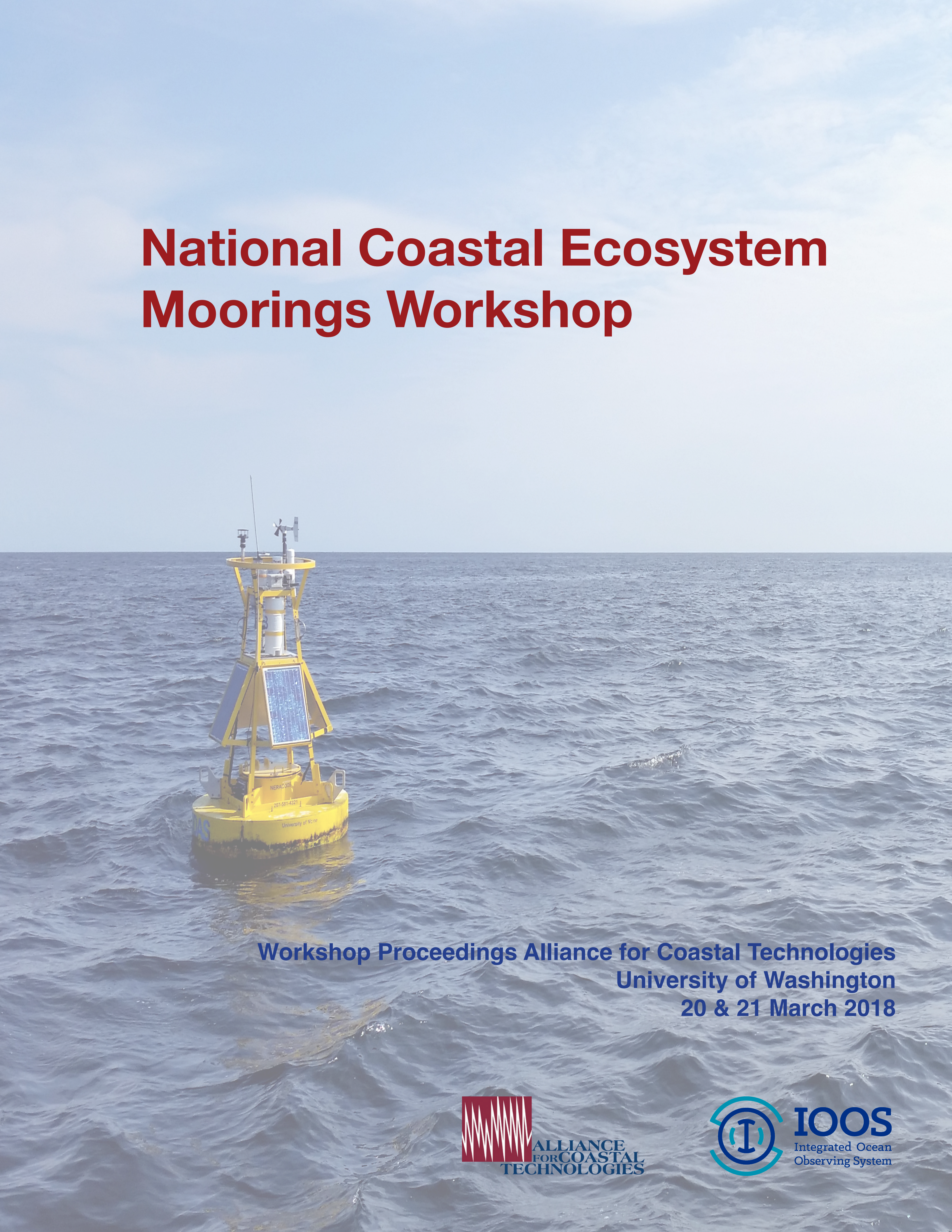

National Coastal Ecosystem Moorings Workshop

Workshop Proceedings Alliance for Coastal Technologies
University of Washington
20 & 21 March 2018

ALLIANCE FOR COASTAL TECHNOLOGIES

IOOS
Integrated Ocean Observing System

[UMCES] CBL 2018-033
ACT WS02-18

Workshop Proceedings
Alliance for Coastal Technologies

NATIONAL COASTAL ECOSYSTEM MOORINGS WORKSHOP

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This workshop was organized and hosted by the Alliance for Coastal Technologies (ACT) and sponsored by the National Oceanic and Atmospheric Administration (NOAA)/US Integrated Ocean Observing System (IOOS)

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EXECUTIVE SUMMARY

The Alliance for Coastal Technologies (ACT, www.act-us.info) convened the "National Coastal Ecosystem Moorings Workshop" in Seattle, Washington at the University of Washington on 20 and 21 March 2018. The primary objectives of this workshop were to: 1) Provide a synthesis of stakeholder information requirements, 2) Explore current and emerging sensors to meet those requirements, 3) Provide a summary of technical needs inclusive of power and telemetry, 4) Provide a summary of deployment logistics, operation and maintenance, 5) Identify tiers/options for ecosystem moorings configurations, dependent on the regions and costs, and to 6) Discuss integration (data management, communications, infrastructure) with other observing systems. The participants were from various sectors including research scientists, technology developers, industry providers, and technology users.

Given the requirements and technical capabilities discussed in the workshop, participants identified three recommendations to define coastal ecosystem moorings.

First, a backbone of core biogeochemical and physical measurements, which are ancillary to ecosystem observations and which *all sites should collect and have in common*: temperature at surface and subsurface to resolve relevant stratification, salinity at surface and subsurface at least to resolve relevant stratification, dissolved oxygen at least subsurface, pressure or depth where sensors are, chlorophyll/backscatter in the surface layer. This backbone of core biogeochemical and physical measurements informs societal issues like hypoxia, harmful algal bloom dynamics, and stress on the food web and allows use of algorithms for ocean acidification calculations. It also gives insights into upwelling and thus is important to inform ecosystem processes.

The participants also proposed ***a recommended suite of measurements,*** which includes the *backbone ancillary measurements, in addition to all or a subset of the following*, based on the regional needs and applications: pH / pCO_2 (both are recommended at the surface, pH is a good option subsurface), color dissolved organic matter (CDOM), nitrate, current velocity, meteorological sensors, passive bioacoustics (including fish tag receivers which are very low-cost), active bioacoustics, and light field - photosynthetically active radiation (PAR). This recommended suite of measurements will help the community to understand processes driving ecosystem variation; advance direct measurement of biology; validate ecosystem models for target species and protected species; and, may lead to the understanding of and predictability of events.

The participants finally identified a ***high-capability suite,*** which are feasible, but costly; therefore, the recommendation is to use the high-capability suite at a subset of sentinel or demonstration sites. This includes the *backbone ancillary measurement in addition to a subset of the following*, based on the regional needs and applications: carbon system variables (more than just pH and CO_2), CDOM, nutrients, current velocity, atmospheric variables, passive bioacoustics, active bioacoustics, light field (spectral), genomic sensors (e.g., harmful algal blooms (HABs), eDNA, toxins), and imaging sensors (e.g., plankton). This high-capability suite enables real-time detection of HABs/toxins; identifies food-web members (plankton and fish) and assesses productivity for informing fisheries management; allows for interpretation of connections driving ecosystem; and, reduces uncertainty and bias in models.

A major impediment to the deployment of many of the sensors that provide quantification of true biology (including biodiversity) as well as chemical variables in the ocean is cost and suitability for moorings. This is a critical time for the government to invest in the development of these sensors in order to bring down the costs and make these sensors more affordable.

Finally, the participants noted that there is a real need to establish an online group to share experiences with coastal moorings. In response, the Alliance for Coastal Technologies is establishing a ***discussion forum***. The discussion forum will be a web-based community exchange forum for regional association (RA) technical/operations staff and coastal ecosystem mooring operators to share lessons learned, exchange information, build towards standardization.

ALLIANCE FOR COASTAL TECHNOLOGIES

One of the greatest challenges that NOAA faces in incorporating advanced technologies is bridging the Technology Readiness Level gap between developmental and operational instrumentation. Efforts dedicated to maturing observing technologies to operational readiness through rigorous and relevant testing, while simultaneously building user confidence and capacity, continue to be critical. Building on over a decade of experience in facilitating the development and adoption of environmental observing instrumentation, the Alliance for Coastal Technologies (ACT, www.act-us.info), works in collaboration with U.S. Integrated Ocean Observing System (IOOS) Program Office and Regional Associations (RAs), IOOS federal and non-federal partners, local and regional resource managers, academic researchers and the private sector to improve operational observation capabilities through the quantification of existing instrument performance, and the introduction of new technologies, and enhanced communications. ACT's mission is to foster the creation of new ideas, new skills, new technologies, new capabilities, and new economic opportunities in support of the sustained national IOOS.

ACT was established by NOAA in 2001 to bring about fundamental changes to environmental technology innovation and research to operations practices. ACT achieves its goal through specific technology transition efforts involving both emerging and commercial technologies with the explicit involvement of resource managers, small and medium-sized firms, world-class marine science institutions, and NOAA and other Federal agencies. ACT's core efforts are:

1) Technology Evaluations for independent verification and validation of technologies,
2) Technology Workshops for capacity- and consensus-building and networking, and
3) Technology Information Clearinghouse including an online Technologies Database.

ACT is the world's leader in the evaluation of commercial and emerging ocean, coastal and freshwater sensing technologies. ACT's Technology Evaluations employ an ISO/IEC 17025:2005 compliant process to generate sensor performance data of known and documented quality through an open, inclusive, and transparent process that is responsive to the *users' operational needs*. Evaluations focus on classes of instruments to demonstrate capabilities/potential of emerging technologies, provide unequivocal verification of performance specifications for commercial technologies, and/or provide validation of instrument operational qualifications that meet users or observing system requirements. Laboratory and field testing is carried out under reproducible, well-understood conditions, which allows manufacturers to assess and improve components, configurations, and designs as necessary. Since 2004, ACT has evaluated nearly 90 sensors from 32 international companies. Results of ACT Technology Evaluations also have provided important insights to users on how to interpret data provided by *in situ* instrumentation and thus how to appropriately quantify various environmental parameters. The ACT Evaluations provide independent 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.

ACT Technology Workshops have addressed the capabilities of existing operational technologies (e.g., dissolved oxygen and salinity) and needs for new technological solutions to address specific global environmental issues (e.g., nutrients pollution and ocean acidification). Encouragement of the private sector as participants not only provides users with opportunities to better understand technology options, but also helps technology providers to better understand customers' needs.

The ACT Information Clearinghouse includes all Technology Evaluation and Workshop reports (as downloadable PDFs) and a stakeholder driven database that compiles and inventories information on observing technologies. The Technology Database now connects users with over 400 companies and nearly 4,000 commercial instruments, which increases awareness of technology customers, users, regulators and policymakers of available technology options.

WORKSHOP GOALS AND QUESTIONS

The overarching goals of the ACT "National Coastal Ecosystem Mooring Workshop" were to: 1) Provide a synthesis of stakeholder information requirements, 2) Explore current and emerging sensors to meet those requirements, 3) Provide a summary of technical needs inclusive of power and telemetry, 4) Provide a summary of deployment logistics, operation and maintenance, 5) Identify tiers/options for ecosystem moorings configurations, depending on the regions and costs, and to 6) Discuss integration (data management, communications, infrastructure) with other observing systems. Specific questions that were discussed during the two-day workshop included:

Breakout Topic #1: Use requirements for ecosystem moorings

i. What ecosystem monitoring work is being done in your region?
ii. Is this current ecosystem monitoring sufficient? If not, what are the problems?
iii. What is required to improve the current systems?
iv. Who are the stakeholders?

Breakout Topic #2: Exploration of current and emerging sensors to meet information requirements

i. What do we measure and how do we measure it?
ii. Which sensors are still in development, and/or need additional investment to meet future requirements?
iii. Which sensors are commercially available?

iv. What are the calibration requirements?
v. Which sensors are prone to biofouling?
vi. What else do we need to consider?

Breakout Topic #3: Summary of technical (e.g. power and telemetry) needs

i. How do you power moorings now? What are present power requirements?
ii. How will we power moorings in the future? What are future power requirements?
iii. How do you control sensors and handle data on the mooring?
iv. How do you communicate with moorings? Are two-way communications necessary?
v. What about communication between moorings and platforms?
vi. How much does adaptive sampling matter?
vii. What else do we need to consider?

Breakout Topic #4: Summary of deployment logistics, operation and maintenance

i. How do we deploy and recover moorings?
ii. How will we deploy and recover moorings in the future?
iii. What are the logistical constraints to deployments (ship availability)?
iv. What duration is optimal for ecosystem moorings?
v. How many systems are needed for continuous operations?
vi. What else do we need to consider?

Breakout Topic #5: Discussion of integration (data management, quality control, communications, infrastructure) with other observing systems

i. Are there commonalities with other observing platforms?
ii. What are the data management challenges?
iii. What are the QA/QC challenges?
iv. How can systems work synergistically to enable optimal outcomes? How do autonomous/intelligent moorings affect operations?

Breakout Topic #6: Implementation recommendations on how to satisfy use requirements, with consideration of regional and logistic constraints.

i. Identification of tiers/options for ecosystem mooring configurations
ii. What is a minimum suite of measurements?
iii. What is a medium suite?
iv. What is a fully comprehensive suite?
v. What are considerations for the future? (What are the technology and capability gaps?)
vi. What recommendations are regionally unique, what are common?
vii. Why moorings and how do they complement other observing platforms?
viii. What else do we need to consider?

ORGANIZATION OF THE WORKSHOP

The National Coastal Ecosystem Moorings Workshop was organized and hosted by the Alliance for Coastal Technologies (ACT, www.act-us.info) and sponsored by NOAA/IOOS on 20 and 21 March 2018 at the University of Washington, Seattle, Washington. An advisory committee comprised of leading experts (Dr. Kathleen Bailey (NOAA/IOOS), Gabrielle Canonico (NOAA/IOOS/MBON), Dr. Shannon McArthur (NOAA/NWS/NDBC), Dr. Ru Morrison (NERACOOS), Dr. Jan Newton (NANOOS/UW), Josie Quintrell (IOOS), and Dr. Uwe Send (UCSD Scripps) assisted Dr. Margaret McManus and Daniel Schar (UHM-ACT), as well as Dr. Mario Tamburri (UMCES/ACT) in planning the workshop. There were 34 participants (Appendix A) selected to represent 3 sectors of the community: academic researchers, government researchers, and those in private industry.

The workshop was opened with a presentation about ACT and overview of the workshop by Professor Margaret McManus (UHM, ACT Co-Principal Investigator), after which time the participants were introduced through informal activities.

After the informal introductions, steering committee experts (Dr. Kathleen Bailey (NOAA/IOOS), Dr. Ru Morrison (NERACOOS), Dr. Jan Newton (NANOOS/UW), Dr. Uwe Send (UCSD Scripps) gave a presentation outlining 'The National Strategy for a Sustained Network of Coastal Moorings'. This presentation was followed by 15-minute presentation describing the goals for the workshop.

After these presentations, the participants were split into four working groups, organized by region: Great Lakes/Northeast/Mid-Atlantic; Gulf of Mexico/SE Atlantic/Caribbean; Pacific Coast; and Pacific Islands/Alaska. The primary objective of breakout topic #1 was to examine use requirements for ecosystem moorings. After breakout topic #1, and a catered lunch, the groups reconvened in plenary, and a chair from each group provided a summary of the group's findings.

Participants were then divided evenly into three groups for breakout topic #2. These groups were not organized by region as before, but rearranged to ensure each group contained an even mix of representation among different sectors. The primary objective of breakout topic #2 was to explore current and emerging sensors to meet information requirements. After the conclusion of breakout topic #2, the groups reconvened in plenary, and a chair from each group provided a summary of the group's findings.

On the second day of the workshop, participants were divided again into three groups. Each group then cycled through three concurrent breakout topics that addressed: breakout topic #3 - technical (e.g., power and telemetry) needs communication and adaptation, breakout topic #4 - deployment logistics, operation and maintenance, and breakout topic #5 - integration (e.g., data management, quality control, communications, infrastructure) with other observing systems. For this round of breakout topics the members of each group rotated from room-to-room, while the leads for each breakout group remained in their assigned room. This was a very successful method to gather a large amount of information very quickly from a large group of individuals.

After breakout topics #3, #4 and #5 the groups reconvened in plenary, and a chair from each group provided a summary of the group's findings. After a steering committee working lunch, the participants were split into the four regional working groups defined for topic #1. The primary objective of breakout topic #6 was to discuss implementation recommendations on how to satisfy use requirements, with consideration of regional and logistic constraints. After a catered lunch, the groups reconvened in plenary, and a chair from each group provided a summary of the group's findings.

The final session in the workshop was a Panel Discussion led by Dr. Kathleen Bailey, Dr. Margaret McManus, Dr. Ru Morrison, Dr. Jan Newton and Dr. Uwe Send. The primary objective of this session was to discuss how outcomes of this workshop could inform ecosystem moorings moving forward. A list of recommendations and action items from this session are described in detail in this report.

THE NATIONAL STRATEGY FOR A SUSTAINED NETWORK OF COASTAL MOORINGS

In October 2015, the National Oceanic and Atmospheric Administration (NOAA) U.S. Integrated Ocean Observing System (IOOS®) Office, along with the NOAA National Data Buoy Center (NDBC), chartered the development of a plan to examine and define the sustained network of coastal moorings surrounding the U.S. coastline, including U.S. territories and the Great Lakes region.

The *National Strategy for a Sustained Network of Coastal Moorings* herein "*NSSNCM*" was developed by a writing team of NOAA federal and nonfederal subject-matter experts and scientists, and led jointly by the U.S. IOOS Office and NDBC. The moorings in the NSSNCM were compiled from IOOS RA data portals and NOAA data center portals and program documentation, with input from observing system operators. Regional lists of moorings were vetted by RA Executive Directors and/or RA Data Management and Communications (DMAC) representatives. The NSSNCM was reviewed by the IOOS RAs and their partners, the U.S. Army Corps of Engineers, NDBC and IOOS Office staff, and the NOAA Observing Systems Council.

The NSSNCM offers a high-level geographic overview of the existing mooring locations and observations to provide a starting point for identifying observational gaps that could best be addressed with coastal moorings. Overall, the Strategy provides ten recommendations to achieve a sustainable national network of coastal moorings:

1. Develop an implementation plan with stakeholder input.
2. Identify mechanisms to sustain priority stations.
3. Consider complementary systems and emerging technologies in the development of a coastal moorings implementation plan.
4. Routinely monitor and assess the design of the national coastal mooring network.
5. Add water temperature and salinity measurements to designated existing NDBC mooring stations.
6. Identify and sustain water column ecosystem moorings at four to eight locations in each of the seven primary coastal regions of the United States.
7. Update and implement the *National Operational Wave Observation Plan*.
8. Promote environmental health and operational safety stewardship and regulatory compliance.
9. Develop coastal mooring network performance metrics.
10. Standardize and integrate data management best practices across coastal mooring networks.

BREAKOUT TOPIC #1:
USE REQUIREMENTS FOR ECOSYSTEM MOORINGS

The primary objective of breakout topic #1 was to explore use requirements for ecosystem moorings. To do this, four questions were posed. These included; 1) What ecosystem monitoring work is being done in your region? 2) Is this current ecosystem monitoring sufficient? If not, what are the problems? 3) What is required to improve the current systems? and 4) Who are the stakeholders?

The workshop participants were divided into four separate breakout groups, each specializing in a specific region:

- Great Lakes, Northeast and Mid-Atlantic
- Gulf of Mexico, Southeast Atlantic and Caribbean
- Pacific Islands and Alaska
- Pacific Coast

The same questions were discussed by each group with respect to the current ecosystem moorings and the specific requirements within their region.

What ecosystem monitoring work is being done in your region?

Each region has developed moorings that measure attributes particular local issues. Common themes are to monitor water quality in support of activities related to the EPA Clean Water Act, harmful algal blooms, fisheries management and ocean acidification.

The quantities and types of mooring vary across the regions but there are some broad commonalities. The majority are bottom mounted moorings measuring temperature, salinity, dissolved oxygen and chlorophyll-a. Some moorings make full water column measurements other just record surface parameters. The number of measurement nodes, and range of parameters, vary on each mooring within and across the regions.
The key regional activities are detailed below:

Great Lakes

- Chlorophyll and temperature profiles at 10 locations
- Nitrate and phosphate surface measurements only at four locations
- Active bio-acoustics at one mooring
- Benthic and water column dissolved oxygen at 10-15 locations
- One mooring with the Monterey Bay Aquarium Research Institute (MBARI)-McLane Research Laboratories (MRL) Environmental Sample Processor (ESP)

Mid- Atlantic

- Surface chlorophyll and dissolved oxygen at 10 locations
- Surface nitrate at one location
- Bottom dissolved oxygen at one location
- Animal tracking at six locations
- pCO2 system at one location
- pH at five locations at the surface and one at the bottom

North East

- Nitrate at depth in three locations and profiling at one location
- Surface chlorophyll and turbidity at one location
- Multiple dissolved oxygen measurements on one buoy system
- Three buoys with dissolved oxygen at multiple depths
- Three buoys with mid water measurements of nitrate and chlorophyll
- One buoy with surface dissolved oxygen, chlorophyll, pCO2, pH, nutrients
- Three moorings with the MBARI-MRL-ESP

West Coast Florida

- Harmful algal bloom moorings deployed by MOTE marine laboratory, Florida Wildlife Research Institute, University of South Florida and the National Centers for Coastal Ocean Science ECOHAB program.
- Ocean acidification moorings in the Florida Keys to support coral reef management studies by NOAA AOML as part of the Integrated Coral Observing Network.

- The Marine Biodiversity Observation Network is assessing biodiversity of coral reef fish using acoustics. The Florida Atlantic Coast Telemetry (FACT) network, with partners from the Bahamas to the Carolinas, uses a network of acoustic sensors to detect fish species and monitor migration. The physical monitoring of surface currents is used as a proxy for larval transport.
- Harbor Branch Indian River Lagoon Observatory uses Land Ocean Biogeochemical Observatory (LOBO) units for estuarine and monitoring along the east coast of Florida in support of extreme event management to protect life and property on the barrier reefs and islands.

Caribbean

- Primarily ocean acidification moorings at La Parguera, Puerto Rico.

Gulf of Mexico

- There are three existing mooring arrays across the Campeche Bank, the Yucatan Channel and the Florida Straits. The National Academy of Sciences has recommended an expansion of these, plus a mooring in the Dry Tortugas, to improve understanding of the Gulf of Mexico Loop Current.
- Gulf of Mexico Coastal Ocean Observing System harvests oil platform data and disseminates it through their real-time data portal.
- Texas Automated Buoy System (TABS) established in 1995, consists of 8 offshore buoys on which currents and meteorological data are monitored.
- Texas Coastal Ocean Observing Network (TCOON). TCOON is a network of platforms that collect water level and other data.

Alaska Chukchi Sea

- Under ice moorings are deployed to establish a baseline for environmental change. They provide important data to communities for fishing, walrus & whale hunting, community sustenance, ice cover, policy & planning, food security, outreach, education and ecosystem management.
- The moorings extend 30 meters from seabed, below ice seasonal cover, and measure temperature, salinity, nitrate, dissolved oxygen, pCO_2, pH, CDOM, turbidity, PAR, multi-frequency active and passive acoustics, sediment traps, water sampler and particle size.
- Open ocean moorings are used for environmental monitoring and emergency response planning. Acoustics provide data on whales, seals, fish, ambient noise, ice noise & conditions and local anthropogenic noise from survey air guns. Measurements include temperature, salinity, dissolved oxygen, chlorophyll-a, PAR, nitrates, ocean currents, wave spectra and acoustics (active and passive).

Alaska Seward

- Real time temperature data are provided for the ocean heat pump system at the Alaska Sea Life Center in Seward.

Hawaii

Kaneohe

- Monitoring is undertaken in support of climate change, ocean acidification, program planning, tourism, coral reefs, outreach and education. Measurements include temperature, salinity, dissolved oxygen, chlorophyll-a, pCO_2, pH and total suspended solids.

Renewable Energy

- Measurements of temperature, salinity, chlorophyll-a, current velocity, total suspended solids to assess environmental change, support local industry and provide data for the seawater air conditioning program.

Hilo, Kauai and Oahu

- Seven coastal and two estuarine buoys measuring temperature, salinity, dissolved oxygen, chlorophyll-a and total suspended solids. Turbidity is used as an indicator for water quality, brown water events and fecal bacteria. Data are used by shell fisheries, oyster production, recreational water users, tourism and for policy planning. The Hawaiian community use these data to record the effect of changes in watershed uses on the water quality in culturally sensitive areas.

Aloha Cabled Observatory

- A bottom mounted observatory north of Oahu measuring temperature, salinity, dissolved oxygen, acoustic doppler profilers and video camera. The data is used for science, education and outreach.

Hawaii Ocean Time Series

- The Woods Hole Hawaii Ocean Time Series (WHOTS) mooring has been providing air-sea flux data since 2004. Measurements include a meteorological suite (air and sea surface temperatures, relative humidity, barometric pressure, wind speed and direction, incoming shortwave and longwave radiation, and precipitation) plus subsurface temperature, salinity, ADCP for water-column current profiles including surface currents.

Arctic and Equatorial Pacific

- Moorings are deployed with wave powered wire walkers generating profiles of temperature, salinity, dissolved oxygen, total suspended solids and pH.

Pacific Coast

- A number of surface buoys and sub-surface moorings in support of biogeochemical, physical, wave and meteorological measurements.

- The common measurements are temperature, salinity, dissolved oxygen and chlorophyll-a. Some moorings are supplemented with pCO2, pH, turbidity and current meters. Specific moorings have additional nutrients, acoustics and optical sensors.

Is this current ecosystem monitoring sufficient? If not, what are the problems?

All the regions agreed that the current level of ecosystem monitoring was insufficient and more comprehensive measurements are required. There are a number of common deficiencies across the regions which result in less than optimal data products for end users. Common problems are: 1) Poor spatial and temporal observations resulting in reduced data density. Modern ocean models require high resolution data driven by long time series measurements to produce suitable products for end users and stakeholders. Lack of observations reduce the ability for adaptive management. 2) A need to better understand interaction between inshore, offshore, pelagic and benthic regions and the interconnectivity on a biological and physical scale. 3) Infrequent biological monitoring reduces ability to assess the state of the ecosystem resulting in long delays to make decisions. 4) Lack of a sustained funding source for long-term mooring deployments. Most are resourced through short-term research funds. 5) Lack of new technologies on existing moorings. In some cases there are no suitable sensors to measure the parameters required (e.g. biodiversity) or they are too expensive (e.g., MBARI-MRL ESP). These sensors are currently expensive because only a few are produced. As the technology continues to evolve it is possible that these sensors may become more accessible. Finally, 6) Biofouling and the long-term calibration of sensors remain a concern. They lead to reduced service intervals for the mooring and higher maintenance costs.

A number of region specific shortcomings were identified with the existing ecosystem monitoring infrastructure:

Great Lakes

- Harmful algal blooms have a significant impact on recreational fishing. There are insufficient observations for HABs and the detection of their toxins. Since the blooms are highly visible to the public they do result in a noticeable reduction in tourism. Real time, in-situ data on HAB toxins will be needed to validate and initialize toxicity forecast models.
- Hypoxia is an indicator for the quality of potable water. There are not enough observations to validate and initialize hypoxia forecast models.

Maine

- The local shellfish (lobster) harvest is impacted by low levels of dissolved oxygen and decreases in the benthic water temperature. More data are required to refine the models for improving commercial and recreational catch limits.

Florida

- Fisheries management would be improved by the wider use of acoustics for aggregation, fish spawning and tracking.
- Larval monitoring should be improved. The current model uses surface currents to assess larval movement but deep-water data are missing.
- There is insufficient monitoring and management of seagrass beds.

Gulf of Mexico

- Hypoxia is a specific concern in estuaries and regions of river influence in the coastal zone such as the Flower Garden Banks National Marine Sanctuary. These areas would benefit from hypoxia-specific mooring measurements. Two buoys no longer deployed in Mobile Bay and the Mississippi River should be reinstated.
- Acoustic monitoring should undertaken on the Flower Garden Banks, Florida coast and in key areas of the Caribbean. These baselines are necessary to understand biological impacts for fisheries management. The Caribbean has seed money to move from land to marine acoustic measurements.
- Ocean acidification measurements should also begin in the Flower Gardens Banks and Caribbean.

Caribbean

- Current ecosystem monitoring is primarily physical and chemical. There is no biological monitoring program.

Pacific Coast

- There is poor spatial coverage and interconnectivity between regions. There are no ecosystem measurements between Coos Bay, Oregon and Bodega, California. Few cross-shelf measurements degrades the ability to fully understand the processes driving ecosystem dynamics.
- Seasonal but sustained observations of HAB species and toxins near Heceta Bank and near the Juan de Fuca eddy can provide valuable early warnings for potential coastal shellfish toxicity.

Pacific Islands and Alaska

- The Pacific Islands and Alaska cover immense coastal regions. More spatial resolution in ecosystem measurements is critically needed.
- An ice breaking buoy system should be developed to enable wider measurements within the Alaska region.

What is required to improve the current systems?

The discussions identified a range of requirements to improve and expand the current ecosystem moorings:

Mooring sensors and systems: Existing moorings require upgrading with a larger number of sensor nodes and with additional parameters. In some cases this could be achieved by the use of profiling systems. Defining a basic biogeochemical sensor suite would establish a baseline upon which other systems could build. It should be noted that there are an ongoing discussions on this topic in the Biogeochemical Argo Initiative (http://biogeochemical-argo.org/). Existing non-ecosystem moorings should be enhanced with this same basic suite. In addition, sensors require an increased service life with extended calibration intervals and should be more resistant to biofouling. The group noted that lower power sensors, together with improved battery capacities, will significantly reduce maintenance costs. Sensors for chlorophyll-a and nutrients require improved detection limits and pH sensors have an unacceptable limited life in seawater. New commercially available biological sensor technologies should be employed, such as the Imaging Flow Cytobot (IFCB), ESP and bacterial sensors. Finally, knowledge from other US agencies, and overseas oceanographic institutions, should be leveraged in order to implement best practices on sensor selection and data integration across moorings.

Integrated systems: The group recommended that in order to achieve greater spatial and temporal coverage, moorings should be a component of an integrated monitoring system. Multiple moorings may be required at one site or distributed throughout a region. Improved onboard processing, with acoustic telemetry between moorings, will enable adaptive sampling in response to ecosystem events. It is important that the correct combination of physical, chemical and biological sensors are available in order to

produce meaningful data products. Modelling and stakeholder input should be used to determine the optimum location for a mooring or array.
Funding: As previously suggested, ecosystem moorings are designed to be deployed for extended periods of time and as such incur capital plus ongoing maintenance costs. Moorings should not operate in isolation but as an integrated suite. Therefore a long-term finance model is required that will provide funding for capital purchases and through life costs for a network of moorings. Improved data products, and well-defined use cases, will ensure greater understanding and engagement by stakeholders. A study of current stakeholder usage and needs, and the societal benefits of moorings and the resulting data products, would enable business cases to be developed.

Who are the stakeholders?

The key stakeholders in ecosystem monitoring and moorings are those organizations and individuals who invest in the systems and make constructive use of the data and data products. These are identified currently as being: State and Federal agencies (including public health agencies), emergency managers / state planners, pollution responders, research scientists, port and harbor authorities, and commercial / recreational marine and freshwater users.

Specific agencies and industry sectors that currently use mooring-derived data products include: US EPA, US Navy, US Coast Guard, US Army Corps of Engineers, US Bureau of Ocean Energy Management, the National Hurricane Center, NOAA Office of National Marine Sanctuaries, NOAA Weather, NOAA Fisheries, NOAA Research, NOAA Ocean Service, US Fish and Wildlife Service, Gulf Coast Ecosystem Restoration Council, local drinking water municipalities, Environment Canada, commercial fishing and shellfish industry, recreational fishermen and boaters (sailors, surfers, beachgoers, divers), tourism and hospitality, private weather services, offshore oil and gas, renewable energy, environmental non-governmental organizations (NGOs), and multiple levels of educators.

Collectively the breakout groups identified a number of ways in which the data from ecosystem moorings are used across the regions by stakeholders: 1) understanding environmental state, variability and change, and providing information for ecosystem-based management; 2) emergency response planning, community sustenance, food security; 3) understanding ecosystem changes and how these affect local economies; 4) understanding the impact of invasive species on the regional economy; 5) hypoxia impacts on sustaining fishing, tribes, and local economies; 6) HAB impacts on fishing, tribes, human health, tourism and local economies; 7) ocean acidification impacts on aquaculture, tribal sustenance, and local economies; 8) sea temperature variations and impacts on commercial fishing; 9) improved knowledge of currents to understand crab pot recoveries; 10) interactions between protected species and fisheries and how these are impacted by regional and ocean events; 11) noise pollution and how this affects species distribution and migrations; 12) carbon cycle research and sequestration; 13) understanding how to achieve renewable energy needs without disrupting ecosystem, and; 14) how to optimize forecasting and nowcasting models support in order to provide societally useful information.

BREAKOUT TOPIC #2: CURRENT AND EMERGING SENSORS TO MEET INFORMATION REQUIREMENTS

The primary objective of breakout topic #2 was to explore current and emerging sensors to meet information requirements. To do this, five questions were posed: 1) What do we measure and how do we measure it? 2) Which sensors are still in development, and/or need additional investment to meet future requirements? 3) Which sensors are commercially available? 4) Which sensors are prone to biofouling? 5) What else do we need to consider?

What do we measure and how do we measure it? Which sensors are commercially available? Which sensors are still in development, and/or need additional investment to meet future requirements?

The following paragraphs describe physical, atmospheric, chemical and biological sensors that are used, or have been used by the workshop attendees, they do not reflect specific ACT evaluations.

Physical sensors

Temperature and Salinity (T and S): This is a proven technology and sensors are commercially available. There is a good user choice available with range of accuracy, resolution, and stability. These data can be telemetered easily, and are suitable for real time or stored data. Salinity accuracy can be improved by good quality assurance/quality control (QA/QC), especially by taking coincident water samples at conductivity, temperature, depth (CTD) stop depths; however, this is time consuming and expensive, so not always carried out.

Pressure and bottom-pressure: Pressure is usually needed to know the depth of a sensor/measurement, a few centimeters error can lead to significant error in salinity calculated from temperature and conductivity. Bottom pressure is also an important dynamical quantity. There is a range of commercial sensors with differing technologies (e.g. Digiquartz, strain gauge) available. The user can select low cost with low accuracy and poor stability through to very high cost high performance sensors.

Currents: Coastal moorings rarely use mechanical current meters. Single point acoustic sensors and/or acoustic Doppler current profilers (ADCP) are now used. For the price of 2-3 single point sensors, the user can get an ADCP, which will give full water column data in coastal regions. ADCP performance is degraded in clear oligotrophic waters, but they do still work in these environments, in extreme cases, with just a reduced range. ADCPs cannot measure near the surface nor near the bottom due to acoustic sidelobes, so if data in these boundary layers are a requirement, additional sensors are needed.

Inverted Echosounder (IES): In coastal regions, this instrument may be useful at high latitudes for measurements of ice draft. The technology is mature and easily available.

Turbulence: There are two common ways to measure turbulence in the marine environment - by measuring high-resolution changes in temperature, or by measuring high-resolution changes in velocity. Rockland-type turbulence sensors need advection or profiling with 25 cm/s or so, and vibration effects can be removed by data processing. These sensors may be feasible where needed for mixed-layer studies or impact of turbulence on plankton.

Atmospheric measurements

Wind speed/direction: Wind speed and direction can be measured acoustically or mechanically; however, mechanical methods are prone to freezing/icing over in winter. Ideally have both types for comparison and redundancy - both are commercially available and technically proven, and the accuracy generally depends on price.

Air temperature and pressure: These sensors are well tested and commercially available

Humidity / Precipitation: The best available sensors for humidity and precipitation do not work well on buoys at sea. The calibration is difficult and most sensors only deliver qualitative data. Nonetheless, for many coastal (ecosystem) applications these sensors may be adequate.

Attitude/motion: The measurement of attitude/motion is important for wind and irradiance data. Inertial motion units (IMU) are inexpensive now. The major push behind the drop in price comes from the drone industry.

Irradiance: The measurement of irradiance or photosynthetically active radiation (PAR) is a proven technology. These sensors are commercially available. The user needs to choose between sensors that: integrate over all short wavelengths; integrate photosynthetically available radiation (PAR); measure discrete wavelengths (typically 5-7); or, are hyperspectral (used for satellite calibrations).

Chemical sensors

Oxygen: The optode (minidot, Aanderaa, Seabird) has a slow response but is quite stable (acceptable for non-profiling applications like moorings). The membrane-based sensor has fast response but this is not considered necessary for moorings. With careful QA/QC these sensors are mature.

Fluorescence/turbidity/backscatter: This technology is mature and available in combination/multi-wavelength packages. The problems with these sensors are biofouling and interpretation of a purely physical (optical) measurement to infer chlorophyll or biomass. Calibrations (factory or standards) account for changes due to aging (light source, etc.).

Nutrients: There are two common technologies used to detect nutrients in the marine environment - optical and wet chemistry. The optical is the SUNA sensor. A recent ACT evaluation (http://www.act-us.info/evaluations.php#Nutrient) carried out in 2016 considered the following wet technologies: System WIZ nitrate and phosphate probe, NOC nitrate and phosphate probe, Real Tech nitrate analyzer, SeaBird Scientific Hydrocycle phosphate analyzer (but all only for shorter deployments). Currently the only sensor used for long-term moored deployments is the SUNA, but it can be difficult to associate laboratory calibrations with *in situ* deployments. The SUNA is power hungry, often has baseline drifts. Good calibrations are critical.

pH: The ISFET/Durafet technology works; however, SAMI has more accuracy but is less reliable when deployed in the marine environment. A shallow Durafet is easier to build and operate, with internal and external electrode (Scripps Martz lab or Seabird). A deep Durafet only has one electrode (Seabird). This technology works, but packaging (electronics, etc.) is sometimes still problematic. Scripps Institute of Oceanography (SIO) sensors have been deployed many times for 1-year durations without problems. Cheaper sensors exist that have lower accuracy and need more frequent calibration.

pCO2: Options/manufacturers are SAMI, ProOceanus, MapCO2, Contros/Kongsberg, but overall less mature than pH. The MapCO2 system at the surface performs well and reliably, but is big and expensive and requires a substantial surface buoy. The ProOceanus is adequate but has a high power requirement. Aanderaa also has a prototype CO2 optode.

DIC and alkalinity: These sensors are only in prototype versions

Biological sensors

Passive acoustics: Passive acoustic sensors are mature, commercially available, and have many different capabilities in terms of bandwidth, sampling frequency, sampling period/on-time, and battery consumption. The major limitation with passive acoustic sensors is their cost. These instruments are also sometimes limited by power availability leading to duty cycle. Absolute calibrations are rare, since these are very difficult/expensive.

Active acoustics: Active acoustic technology exists, and there are many commercially available options (single/split-beam, multi/broad band) that range in price from inexpensive to very expensive, and there are many commercially available options. There are some power-hungry and large/heavy sensors. The challenge with active acoustics is mainly in interpretation of the data. On a side note, active acoustic sensors need environmental permits, as do ADCPs.

Tagging/fish telemetry: Tagging/fish telemetry receivers are cheap and simple. Many in the group felt that these sensors should be added to all moorings. Radio receivers for birds/bats (radion, ultrasound), on surface moorings are feasible.

Sediment traps: McLane water sampling systems (small number of samples) are available. It is also possible to construct your own sediment traps for short deployments for a fraction of the cost.

Imaging systems: There are many different prototypes for example plankton microscopic imaging (e.g. the Imaging Flow Cytobot (IFCB)), the Laser Optical Plankton Counter (LOPC), the Spatial Plankton Analysis Technique (SPLAT CAM), the Sequoia LISST, ZooCAM, Dual-frequency Identification SONAR (DIDSON), and the In Situ Icthyoplankton Imaging System (ISIIS). However, these imaging systems are usually not designed for moorings. The major limitations for imaging sensors are the size of the data sets they generate and data analysis, as well as power requirements. In addition, to our knowledge, none of them are ready for long-term deployments where shore power is not available.

Genomics: The Environmental Sample Processor (ESP) was developed by Chris Scholin and colleagues at MBARI, and is now commercially available from MRL. The ESP is the one known autonomous genomic sensor that can be deployed in an oceanographic or freshwater (e.g., Great Lakes) environment. Phytoplankton metabolites (e.g., HAB toxins) can also be measured in situ by the ESP. The primary limitations for the ESP are cost and the need for customized, third-party sensors/assays for location-specific target organisms and metabolites/toxins.

Automated water samplers: Several types of autonomous water samplers are available commercially from MRL (Remote Access Sampler (48 sample capacity); Phytoplankton Sampler (24 sample capacity). The ESP can also be used to filter and archive particulate samples. Cost, limited sample capacity, and the need for post-deployment, lab-based analyses (vs. near-real or real time in situ analyses) are the main impediments.

Which sensors are not commercially available (for *in situ*)?

In addition to the detailed list given in the previous section, the attendees discussed that there are many instruments that can measure oceanographic attributes in the laboratory, but are not suitable for the marine environment. The attendees would like to see the capability for *in situ* measurements of the following: DIC, alkalinity, ammonia, genetics/genomics sensors/DNA chip, "lab on a chip", radiation sensor, trace elements, mass spec (heavy metals), microbial sensors (alpha, fluorescence), E. coli, etc. (water quality measurements), plastics, hydrocarbons, and anthropogenic tracers.

By taking water samples in the field, transporting the samples to the lab where they are processed, one introduces a significant time delay between sampling and results.

What are the calibration/validation requirements?

The attendees discussed the stability of individual instruments in terms of the production environment (or the population of instruments produced at the same time), the laboratory environment and the field environment.

Several calibration steps were recommended: 1) cross-sensor calibrations/validation in the laboratory setting before the instruments are deployed; 2) pre- and post-calibration of individual instruments before and after deployment; and, 3) development of auto-calibration capability during deployment.

The group stressed the need for instrument users to work closely with industry to make sure calibration techniques are sufficient.

Which sensors are less prone to external biofouling?

The attendees discussed biofouling, as it is a challenge in many environments for long deployments. Several methods to decrease biofouling were discussed, for example: bio-wipers, poison inserts, ultraviolet light, hot pepper sauce, copper tape, proper design (meaning smoother surfaces, fewer hydraulic steps, coating). For sustained measurements, the community needs field-proven methods to reduce biofouling.

There was some discussion regarding those sensors that do not experience as much biofouling (exposed surfaces mean more biofouling). Acoustics, temperature sensors, and pressure sensors were cited as three types of instruments that do not foul as quickly as others; however, these instruments do foul in the long term and sustainable solutions to biofouling for long deployments are needed.

What else do we need to consider?

At the end of our sessions, the attendees recommended also considering: 1) biofouling on the mooring platform itself; 2) the known mismatch between sensor and platform longevity; and, 3) the issue of waste collection.

BREAKOUT TOPIC #3: TECHNICAL NEEDS

The purpose of breakout topic #3 was to discuss technical needs (e.g., power and telemetry). Seven groups of questions were posed in the breakout groups: 1) How do you power moorings now? What are present power requirements? 2) How will we power moorings in the future? What are future power requirements? 3) How do you control sensors and handle data on the mooring? 4) How do you communicate with moorings? Are two-way communications necessary? 5) What about communication between moorings and platforms? 6) How much does adaptive sampling matter? 7) What else do we need to consider?

How do you power moorings now? What are present power requirements?

The present conventional methods of powering moorings are batteries, wind power and solar power.

The NCEM workshop attendees came from a wide range of backgrounds, and service ocean moorings that range from very expensive, high-end moorings like Ocean Observatories Initiative (OOI) to less expensive more mobile moorings.

The OOI is funded by the National Science Foundation and is managed and coordinated by the OOI Program Office at the Consortium for Ocean Leadership (COL), in Washington, D.C. COL is leader, owner, and operator of the OOI and its infrastructure. Implementing Organizations (IOs), subcontractors to COL, are responsible for construction and development of the different components of the program. Woods Hole Oceanographic Institution is responsible for the Coastal Pioneer Array and the four Global Arrays, including all associated vehicles. Oregon State University is responsible for the Coastal Endurance Array. The University of Washington is responsible for cabled seafloor systems and moorings. Rutgers, The State University of New Jersey, is implementing the Cyberinfrastructure component, which now includes the education and public engagement software. The OOI Data Management team is co-located with the

Cyberinfrastructure group at Rutgers University. Some OOI Moorings have power generation from wind and solar. The sensors are dependent on the power system, and without this power the mooring has to be shut down. There is a distinct tradeoff between sampling frequency, available power and turnaround time. For example, if wind or light levels decrease it becomes necessary to slow down the sampling interval so that power is not drawn down as quickly. In addition to power, site accessibility and biofouling are also critical when considering how often moorings need to be turned around.

In locations like Alaska, where ice covers the region for approximately 6 months of the year and many of the moorings are in remote locations, it is difficult to turn buoys around more than annually due to costs and ship time. Subsurface moorings are often the solution in these regions due to ice; however, that limits power generation from wind and/or solar. The power solution for these types of moorings is battery packs. While, many researchers would like to have more power-hungry instruments (e.g., SUNA) on moorings, power limitations often restrict this choice of sensor.

How will we power moorings in the future? What are future power requirements?

The group discussed the fact that lithium batteries can be shipped but require the shipper to have special training and the arrangements take time. This can be problematic and quite often the batteries have to ship separately from the instruments. The group noted that battery technology is rapidly improving and would get better in the next 5 to 10 years. Given the rapid growth in power technologies, it is important to stay current with what is available. For example, solar panels are three times more efficient today than batteries. As for wind power generation, OOI has technology now that is reliable. There was a call from meeting attendees to leverage the OOI experience.

The group voiced interest in learning about options for wave or tidal generated power for moorings.

How do you control sensors and handle data on the mooring? How do you communicate with moorings?

The question of communicating with the moorings naturally brought up the subject of data transmission. Six major modes of data transmission (and their shortfalls) were identified (Table 1).

Table 1: Six major modes of data transmission and their shortfalls

Method of Transmission	**Issues**	**Comment**
Cell phone	coverage	positioning a booster or relay can improve communications
Iridium	bandwidth and cost	a call for less expensive satellite transmission
Fleet broadband	power and cost	
Short-range wifi	Routine checks	
Spread spectrum	line of sight; distance and atmosphere	
VHF wireless over the horizon		

In some regions, like Alaska, where surface expressions are not possible for moorings due to long periods of ice coverage, the data are stored on the instruments – and data are uploaded to databases after the moorings are recovered.

For sensors, using passive acoustics as an example, that have extremely large data streams, researchers are employing on board processing. The post-processed summary data are then the only data that are transmitted. Once the sensor is recovered, the full dataset can be uploaded. As a second example, the OOI moorings are somewhat limited in data transmission, so high-bandwidth data are internally recorded and recovered with the instrument/mooring.

Are two-way communications necessary?

Two-way communications were viewed necessary in terms of adaptive sampling. The ability to change sampling frequency has a direct impact on the power draw of the instrument and mooring. Two-way communication also allows the operator to troubleshoot, reset and track the mooring.

With a sensor suite like the Environmental Sample Processor (ESP) two-way communications are important to allow adaptive sampling as conditions change. This allows the researchers to target specific events (often based on data from co-deployed contextual/physico-chemical sensors), modify sample frequency and volume filtered, and troubleshoot.

There was a call to move to subsurface data transmission using a short-range, low cost acoustic modems, or some cheap way to telemeter data subsurface. However, it was noted that this is very difficult to achieve reliably.

What about communication between moorings and platforms?

Some OOI moorings communicate with other bottom platforms with acoustic modems. This is low bandwidth communication of engineering data. For example, using gliders to map features and relay information to moored sensors. This ability allows better characterization of features and events.

How much does adaptive sampling matter?

Adaptive sampling is a sampling technique that is implemented while a survey is being undertaken. The sampling design is modified in real-time as data collection continues—based on what has been learned from previous sampling. Adaptive sampling allows the researcher to gather critical information and adapt to the changing environment. This is critical for better characterization of features and events as well as improved efficiency of power consumption and use of expendable onboard reagents/supplies.

What else do we need to consider?

During the discussion, several attendees pointed out that ice cover can pose a significant challenge. It was clear that observations in real-time during the ice season are needed, but the transmission of data in near real time in this environment has not yet been attained.

It was noted on several occasions that power supply is not always the limiting factor in the length of deployment. Biofouling and data transmission also play a significant role in how often the mooring needs to be serviced.

It was also noted that while solar panels are an increasingly common way to power some moorings with surface expressions, the threat of vandalism is quite real. Some attendees have stopped using solar panels because they are often stolen.

The attendees also noted that there is a real need to establish an online group to share experiences with coastal moorings. In response, the Alliance for Coastal Technologies is establishing a discussion forum. The discussion forum will be a web-based community exchange forum for RA Technical/Operations Staff and Coastal Ecosystem Mooring

Operators to share lessons learned, exchange information, build towards standardization, etc. This endeavor will involve personnel from the Chesapeake Biological Laboratory, University of Hawaii at Manoa and the University of Louisiana Lafayette.

BREAKOUT TOPIC #4: DEPLOYMENT LOGISTICS, OPERATION AND MAINTENANCE

The primary objective of breakout topic #4 was to explore deployment logistics, operation and management. To do this, six questions were posed. These included: 1) How do we deploy and recover moorings? 2) How will we deploy and recover moorings in the future? 3)What are the logistical constraints to deployments (ship availability)? 4) What duration is optimal for ecosystem moorings? 5) How many systems are needed for continuous operations? 6) What else do we need to consider?

Methods of mooring deployment/recovery now

For existing moorings, there is currently a very large range in the size of the moorings, in the effort (operation), and in the ships used for mooring service (deployment and recovery). Rather than listing many different variations, it was found useful to separate these into two larger categories. If the categories are broadened enough, most moorings will fall into the one or the other category. Also for future moorings, we find this classification useful since it guides a number of aspects (number of sensors, offshore locations/distance from home port, calibration and QC capabilities, multi-disciplinarity, etc.).

Small, nearshore moorings: Many nearshore (shallow) moorings are small and lightweight, and use very small boats. In some cases the mooring may even be towed to its site since the boat cannot handle the size/weight, and the owners employ minimal teams for the operation. This has advantages and drawbacks. The advantage is that frequent servicing or cleaning (by divers maybe) is possible, no expensive acoustic releases are required, and duplicate equipment for swapping the mooring out is often not needed (one can bring a mooring home, service/clean sensors, and then go out and re-deploy with minimal delay). Also the vessels are less expensive, sometimes private charters or fishing boats are used. The drawback is that these are often not "research cruises" that would undertake useful water sampling, CTD casts, net tows, etc. Calibration and ground truthing data for small nearshore moorings are not as consistent.

Large, offshore moorings: Deeper ocean moorings require larger hardware (heavy anchors, acoustic releases, more wire/rope), and thus larger vessels. The disadvantages are: they need larger mooring and sensor teams, the cost is high also due to the larger vessel, infrequent servicing/access requires more robust technologies, there is less flexibility in scheduling, and mooring/sensor turn-around at sea requires duplicate moorings/sensors or more time at-sea for servicing hardware on the vessel. In those cases, 1-year deployment durations must be an objective to keep the costs manageable. Advantages are: larger teams can participate for extensive *in situ* sampling (biological/chemical water samples, net tows, benthic sampling), calibration and validation are more consistent, more capable moorings can be deployed, several moorings can be serviced on a single trip (depending on deck space/load), more remote sites are reachable (both in terms of offshore distance and distance from a staging port), and operations are less sensitive to weather.

Recommendations

Ship Coordination: The needs for ships in each region need to be coordinated across agencies, operators, and users (federal, state, university, private). Often there are multiple ships in the same region all spending transit days to get there. For this it is essential to exchange information better, including NOAA Ship Okeanos Explorer cruises, and including private ships (oil industry, fishing vessels, etc). An effort should be made to share ships where possible, to look at "cruises of opportunity", and to allow/explore swapping staff for a few days at nearby ports. For example during a 3-week California Cooperative Oceanic Fisheries Investigations (CalCOFI) cruise, an SIO mooring team recently boarded the ship for one day to deploy a mooring that had been previously loaded onto the ship. The SIO mooring team was picked up nearshore using a NOAA National Marine Sanctuary boat, and dropped off near the coast using a private water taxi.

Site selection: For choosing sites and coverage with moorings, it is important to consider the proximity of ships, ports, and mooring groups (for deployment and servicing), and also to take into the account the value of co-located complementary measurements (ship programs, gliders, etc.) for cross-calibration and for providing additional information in the space-time domain.

Data quality: Quality control is possibly the most challenging problem. Due to the different types of mooring operations (see above), the data quality is vastly different across sites and operators. Some best practices should be established and possibly required for a site to "qualify" as member of the network. On larger vessels, calibration data should be collected in the field for all sensors that are feasible. Pre-deployment and post-recovery calibrations must be required for any mooring deployed, either from the sensor manufacturers, or from the lab, or from calibrations at sea. Validation of moored sensors from co-located CTD casts/water samples is highly desirable – even small vessels can take water samples and this needs to be encouraged. Maybe we have to live with two classes of data in terms of quality (sometimes called "weather quality" and "climate quality"), but in any case data quality must be specified/quantified, since data without stated accuracy are of low value. Existing material regarding QA/QC procedures from e.g. the OOI, OceanSITES, ACT, etc can be disseminated.

Deployment duration: For nearshore sites this is not a problem since they are easy to access and service. However, for remote sites it is recommended to push for 1-year durations, since this will make sustaining them more feasible (ship availability) and it will lower cost, which ultimately allows more moorings to be implemented with the same amount of funding.

Safety: It is strongly encouraged to check safety rules of the funding agencies, the universities, and the U.S. Coast Guard certifications or insurance of the vessels to be used. Pre-deployment risk analyses are also recommended.

BREAKOUT TOPIC #5: DISCUSSION OF INTEGRATION WITH OTHER OBSERVING SYSTEMS

The primary objective of breakout topic #5 was to discuss the integration (e.g., data management, quality control, communications, infrastructure) with other observing systems. To do this, four questions were posed. These included: 1) What are the data management challenges? 2) What are the QA/QC challenges? 3) How can systems work synergistically to enable optimal outcomes? 4) How do autonomous/intelligent moorings affect operations?

What are the data management challenges?

- Imaging devices produce large volumes of data, which are not in standard formats, making cataloging difficult.
- Linking with other data on the same, or other, moorings within a region, nationally and internationally.
- Important to have correct metadata combined with sensor data in order to provide meaningful data for managers.
    - Configuration of sensor and metadata must be planned before deployments.
    - There is a current activity to ensure NOAA metadata meets international standards.
    - Metadata are often entered into free form data fields, which causes problems. Potentially need to adopt standard vocabularies.
    - IOOS is moving to Darwin core reporting standards.
- OBIS (Ocean Biogeographic Information System) does not accommodate all data (a workshop in February of 2018 discussed this with the measurement community).
- There is a disconnect between program managers and data analysts.

    - Program managers do not necessarily have a say in which types of sensors are purchased for their moorings.
- No data standards for data formats for sensor manufacturers.
    - There are examples of managers (eg USGS) working with industry (Sontek) to ensure sensor outputs are easily handled by customer database.
    - The cost of optimizing sensor data formats is an issue due to the size of the market.
    - Important that all end users agree on the data formats in order to give industry a clear requirement.
- Need formal, regular feedback from data users (learn from Ocean Networks Canada and run annual customer surveys).

What are the QA/QC challenges?

- The metadata does not necessarily indicate the extent of QC applied.
- Some user groups are more advanced in the adoption and use of IOOS' Quality Assurance of Real Time Oceanographic Data (QARTOD) standard. Others do not use it and undertake their own QA/QC due to time and cost constraints.
- Some variables are not sufficiently mature for development of a QARTOD manual.
- Sensor calibration and servicing costs are not always part of the operational budget. QA/QC needs to be an "appropriate budget burden".
- Should mooring managers QC their own data? They archive data but often do not have the staff to QC all the data they receive. Often they develop software routines to flag erroneous data.

QA/QC Custody Chain - challenges

- There are multiple levels in the custody chain and it may not be clear where QC responsibilities lie.
- Sensor manufacturers have responsibility for design proving and calibration traceable to national standards.
    - Need to ensure QA/QC flows from manufacturer to end user.
    - Need to include manufacturers in discussions on QA/QC (they are for QARTOD manual development).
    - Users accept manufacturers' calibration data and operational recommendations.
    - Manufacturers are required to supply calibration certification and evidence of traceable procedures.
- Problems can arise when subsequent calibrations and/or servicing are required. Sensors are not always returned to the manufacturer and QC traceability can be broken.

- Funding for service and calibration should be recognized as a core, acceptable operational cost.
- Calibration by the user can be acceptable but does miss the opportunity for servicing, which the manufacturer undertakes prior to calibration.
- There is no formal link between users on their experiences with equipment. As a result, knowledge of sensor problems, techniques, etc., are not readily shared.
- Manufacturers can be slow to widely communicate known problems, upgrades, etc.
- The QA/QC chain requires prior knowledge of the end user requirement (i.e., are the data used for scientific research or for formal reports and critical data products?)

How can systems work synergistically to enable optimal outcomes? How do autonomous/intelligent moorings affect operations?

Integration between systems:

- Separate or adjacent moorings can have different sampling rates making it difficult to combine temporal and spatial data.
- Moorings can provide a core set of measurements that can then be used by passing ships or gliders for calibration and system checking (AOOS does this with their Chukchi Sea mooring).
    - o NOAA encourages ships to undertake a CTD profile near moorings and gliders often circle moorings to check operation.

BREAKOUT #6: IMPLEMENTATION RECOMMENDATIONS

The primary objective of breakout topic #6 was to discuss implementation recommendations on ecosystem moorings with respect to how to satisfy use requirements, with consideration of regional and logistic constraints. Objectives were to: 1) Define the requirements and users; 2) Identify tiers/options for ecosystem mooring configurations; 3) Discuss what the considerations are for the future, including technology and capability gaps; 4) Discuss what recommendations are regionally unique; 5) Identify unique contributions of moorings and how they complement other observing platforms.

What are the societal needs & stakeholders that define the requirements?

Participants first focused on defining the uses and users of coastal marine ecosystem mooring data. These were:

- Hypoxia impacts on sustaining fishing, tribes, and local economies.

- HAB impacts on fishing, tribes, human health, and local economies.
- OA impacts on aquaculture, tribal sustenance, and local economies
- Temperature variation as relates to fishing and ecosystems.
- Currents to understand crab pot recoveries
- Interactions between protected species and fisheries and how these are impacted by ocean events (e.g., ENSO etc.), climate change (e.g., when whale migrations shift into crab pots and entanglements occur etc.).
- Noise pollution and how this affects species distribution and migrations.
- Understanding ecosystem shifts and how these affect economies.
- Availability of forage species is a huge gap and affects higher trophic levels linked to economies.
- Carbon cycle research and sequestration
- Understanding how to achieve energy needs/export without disrupting ecosystem health.
- Forecasting/nowcast model support: how to optimize in order to provide societally useful information
- Invasive species: e.g., eDNA, IFCB, etc.

Identification of tiers/options for ecosystem mooring configurations

Given the requirements and technical capabilities discussed in the workshop, participants identified three recommendations to define coastal ecosystem moorings.
First, a backbone of core biogeochemical and physical measurements, which are ancillary to ecosystem observations and which *all sites should collect and have in common*: temperature at surface and subsurface to resolve relevant stratification, salinity at surface and subsurface at least to resolve relevant stratification, dissolved oxygen at least subsurface, pressure or depth where sensors are, chlorophyll/backscatter in the surface layer. This backbone of core biogeochemical and physical measurements informs societal issues like hypoxia, HAB dynamics, and stress on the food web and allows use of algorithms for ocean acidification calculations. It also gives insights into upwelling and thus is important to inform ecosystem processes. This first recommendation is very close to the recommendation made by Chavez et al. 2018[1].

The participants also proposed ***a recommended suite of measurements,*** which includes the *backbone ancillary measurements, in addition to all or a subset of the following*, based on the regional needs and applications: pH / pCO_2 (both are recommended at the surface, pH is a good option subsurface), color dissolved organic matter (CDOM), nitrate, current velocity, meteorological sensors, passive bioacoustics (including fish tag

[1] Chavez FP, U Send and D Wallace. 2010. A Minimalist OceanSites Interdisciplinary Network (MOIN). SOLAS Newsletter Issue 11: 25-27. www.solas-int.org.

receivers which are very low-cost), active bioacoustics, and light field - photosynthetically active radiation (PAR). This recommended suite of measurements will help the community to understand processes driving ecosystem variation; advance direct measurement of biology; validate ecosystem models for target species and protected species; and, may lead to the understanding of and predictability of events.

The participants finally identified a ***high-capability suite,*** which are feasible, but costly: therefore, the recommendation is to use the high-capability suite at a subset of sentinel or demonstration sites. This includes the *backbone ancillary measurement in addition to a subset of the following*, based on the regional needs and applications: carbon system variables (more than just pH and CO_2), CDOM, nutrients, current velocity, atmospheric variables, passive bioacoustics, active bioacoustics, light field (spectral), genomic sensors (e.g., harmful algal blooms (HABs), eDNA, toxins), and imaging sensors (e.g., plankton). This information enables real-time detection of HABs/toxins; identifies food-web members (plankton and fish) and assesses productivity for informing fisheries management; allows for interpretation of connections driving ecosystem; and reduces uncertainty and bias in models.

Several considerations and questions for the future were identified. These are listed below, although they are not in any order of priority.

Considerations for the future

- A “mooring” may be multiple moorings at one site in order to fill needs.
- Profiling moorings are highly optimal for some areas, especially where stratification occurs.
- There is a strong need for low-cost, real-time capability for more systems, with on-board processing.
- The community should work hand-in-hand with ocean and food-web modelers and economists (who link to stakeholders) to see what data give the most return. Using models and stakeholder input is essential for defining needs for siting moorings.
- How can cross-agency communication be improved to take advantage of the Coastal Ecosystem Mooring Network?
- It is important to leverage and coordinate with other mooring-based initiatives focused on biogeochemical measurements (e.g., Biogeochemical Argo).

What recommendations are regionally unique? What are common?

Though the various regional groups developed somewhat different lists, when in plenary a consensus was found such that there was agreement on the sensors. All participants noted the appropriateness of application-based (e.g., HABs vs. fisheries) suites of sensors. There were obvious differences when considering ice applications, coral applications and profiling depth due to different environments.

Why moorings and how do they complement other observing platforms?

Moorings can return more power-hungry data than mobile platforms. While moorings cannot resolve spatial variability, they do not mix spatial and temporal variability – they observe the actual Eulerian variability at fixed points (resulting from local changes and from advection of spatial gradients, all of which contribute to fixed-point changes). Moorings are adaptable and can accommodate new payloads and leverage resources. One mooring can yield many different measurements, as well as support many applications. They are a platform to facilitate experimental work in a known environment. Moorings collect data continuously, reveal long-term trends at fixed locations, and allow researchers to quantify ecosystem variability and change. Overarching is the recognition that moorings are one tool that complement other observing platforms, cruises and remote sensing technologies, and ocean observing strategies must exploit the advantages of all for the optimal system.

FINAL PANEL DISCUSSION

The final session in the workshop was a Panel Discussion led by Drs. Kathleen Bailey, Margaret McManus, Ru Morrison, Jan Newton and Uwe Send. The primary objective of this session was to discuss how outcomes of this workshop could inform ecosystem moorings moving forward. The final panel session considered the main findings of the workshop and the next steps required to take forward the workshop recommendations and the National Implementation Plan.

Funding

A ‘Close the Gaps Campaign’ is needed to identify specific use cases for operational ecosystem moorings. This approach has been successful in previous years in conveying similar needs to Congress. The IOOS Regional Associations (RAs) have had good success with use cases focused on HF radar and gliders, where they identified five regional / event gaps that were subsequently funded. This same approach should be considered for a National Coastal Ecosystem Moorings Network, with each RA establishing use cases that strongly promote the requirement and demonstrate the need for a network of ecosystem moorings in language that motivates funders.

In addition, a major impediment to the deployment of many of the sensors that provide quantification of true biology (including biodiversity) as well as chemical variables in the ocean is cost and suitability for moorings. This is a critical time for the government to invest in the development of these sensors in order to bring down the costs and make these sensors more affordable.

National Implementation Plan

The 'National Strategy for a Sustained Network of Coastal Moorings' should have been an implementation plan informed by capability gaps and stakeholder needs. The National Strategy, in its current form, cannot be considered an implementation plan because regional input is lacking. Such a plan will require extensive outreach to RAs, the regions and wider stakeholders. Engagement could be at the RA or the large marine ecosystem level (thereby incorporating multiple RAs in discussions). Key messages based on value added products should target public stakeholders.

The technical requirements for the ecosystem moorings, and the number required, will vary for each RA. However, the minimum sensor configuration should be specified. Discussions should also include interoperability and common standards that support both regional and national needs.
The workshop recommendations should be distributed and communicated regionally through each RA. The implementation plan should include a technology readiness review that encompasses indicative levels of funding required to attain and maintain the monitoring goals. This should include capital purchase costs and through life support, deployment, and recovery. It should also consider technology transfer, real time data and control, and QA/QC procedures. It should show an understanding of what is already in place, the cost to build on existing moorings, and cost estimates for building new, fully fitted ecosystem moorings. Cost-sharing opportunities should be considered.

Community Interaction and Exchange

There is a real need to establish an online group to share experiences with coastal moorings. In response, the Alliance for Coastal Technologies is establishing a ***discussion forum***. The discussion forum will be a web-based community exchange forum for regional association (RA) technical/operations staff and coastal ecosystem mooring operators to share lessons learned, exchange information, build towards standardization.

Ocean Obs '19

To meet the conference timescales Kathy Bailey has already submitted an abstract for consideration. A manuscript / white paper is being developed to be published in *Frontiers in Science*. The manuscript, in partnership with scientists in Australia, will focus on linkages with, and benefits to, users and stakeholders. It should identify a number of concise use cases.

It was suggested that other aspects, such as use cases and the proposed roadmap for the implementation plan, could be presented at Ocean Obs ‘19 as presentations and/or posters.

It was noted that white papers will help develop the conference themes of Ocean Obs 19. The sessions and structure of the conference are still very open and in draft form. Jan Newton and Frank Muller-Karger are on the conference planning committee.

Workshop delegates should advise the Steering Committee if they wish to be a co-authors of the manuscript. This manuscript is in addition to this report.

Next Steps

Participants felt it was important to identify who should carry the ecosystem moorings dialogue forward and how this should be communicated. One suggestion was a series of workshops that involve RAs, IOOS and other partners/stakeholders, in which discussions consider local use cases, requirements, and costs.

Since this is developing a National Strategy it was suggested that one key region is identified to initiate the next step. This could be a California / Oregon / Washington RA workshop that would consider gap analysis and use cases.
It is important that clear recommendations and outcomes are generated that can be communicated at the local and interagency level.

There is a report from each monthly IOOS meeting so mooring topics can be brought up at that time. As discussions progress, or ecosystem moorings come online, details should be shared across the network.

It was commented that this was a U.S.-centric workshop. There is need to investigate, and learn from, other international regions that have established a network of moorings and ecosystem monitors.

APPENDIX A: PARTICIPANTS/CONTACTS

Front row left to right: C Sabine, ID Walsh, JB Mickett, D Wilson, K Bailey, J Dorton, R Allee, K Grissom, JA Newton, C Hall, AN Netburn, G Doucette, S Ruberg, C Janzen. Second row left to right: FE Muller-Karger, J O'Donnell, E Verhamme, R Burt, JR Morrison, MA McManus, N Pettigrew, T Mudge, C Berchok, S Danielson, EP Dever, S Colbert, EM Nosal. Middle row cluster on right (right to left) R Butler, J Crawford, CJ Harvey. Not pictured: S Buschang, G Canonico Hyde, F Chavez, R Esteves, R Green, BD Melzian, D Schar, U Send, J Todd, S McArthur, J Quintrell

Steering Committee in Attendance

Richard Burt
Alliance for Coastal Technologies
rburt@me.com

Kathleen Bailey
NOAA IOOS Program office
kathleen.bailey@noaa.gov

Margaret McManus
University of Hawai'i at Mānoa, Alliance for Coastal Technologies
mamc@hawaii.edu

J. Ruairidh (Ru) Morrison
Northeastern Regional Association of Coastal Ocean Observing Systems
Ru.Morrison@neracoos.org

Jan Newton
University of Washington
janewton@uw.edu

Daniel Schar
University of Hawaii at Manoa, Alliance for Coastal Technologies
schar@hawaii.edu

Uwe Send
Scripps Institution of Oceanography
usend@ucsd.edu

Steering Committee Not in Attendance

Gabrielle Canonico Hyde
U.S. Integrated Ocean Observing System (U.S. IOOS)
gabrielle.canonico@noaa.gov

Shannon McArthur
NOAA National Data Buoy Center
shannon.mcarthur@noaa.gov

Josie Quintrell
IOOS Executive Director
josie@ioosassociation.org

Mario Tamburri
ACT and University of Maryland Center for Environmental Science
tamburri@umces.edu

Participants in Attendance

Rebecca J. Allee

National Oceanic and Atmospheric Administration's (NOAA) Office for Coastal Management (OCM), Gulf of Mexico region

becky.allee@noaa.gov

Catherine Berchok

Alaska Fisheries Science Center (NOAA)

catherine.berchok@noaa.gov

Steve Buschang

Texas General Land Office

Steve.Buschang@GLO.TEXAS.GOV

Richard Butler

Xylem - Aanderaa Instruments

Richard.M.Butler@xyleminc.com

Francisco Chavez

Monterey Bay Aquarium Research Institute (MBARI)

chfr@mbari.org

Steve Colbert

University of Hawai'i at Hilo, PacIOOS

colberts@hawaii.edu

Jim Crawford

Turner Designs

Jim_Crawford@turnerdesigns.com

Seth Danielson

University of Alaska Fairbanks

sldanielson@alaska.edu

Edward Paul Dever
Oregon State University
edever@coas.oregonstate.edu

Jennifer Dorton
Southeast Coastal Ocean Observing Regional Association
jdorton@secoora.org

Gregory Doucette
NOAA/National Ocean Service/National Centers for Coastal Ocean Science
greg.doucette@noaa.gov

Rene Esteves
University of Puerto Rico Mayagüez (UPRM)
rene.esteves@upr.edu

Rebecca Green
U.S. Department of Interior's Bureau of Ocean Energy Management (BOEM)
rebecca.green@boem.gov

Karen Grissom
NOAA National Data Buoy Center (NDBC)
karen.grissom@noaa.gov

Candice Hall
NOAA-Affiliate, National Data Buoy Center (NDBC)
candice.hall@noaa.gov

Chris Harvey
NOAA Northwest Fisheries Science Center
chris.harvey@noaa.gov

Carol Janzen
Alaska Ocean Observing System
janzen@aoos.org

Brian D. Melzian
U.S. Environmental Protection Agency (EPA)
Melzian.Brian@epa.gov

John B. Mickett
University of Washington Northwest Environmental Moorings (NWEM) Lab
mickett@uw.edu

Todd Mudge
ASL Environmental Sciences Inc
tmudge@aslenv.com

Frank E. Muller-Karger
University of South Florida
carib@usf.edu

Amanda N. Netburn
NOAA Office of Ocean Exploration and Research
amanda.netburn@noaa.gov

Eva-Marie Nosal
University of Hawaii at Manoa
nosal@hawaii.edu

James O'Donnell
Connecticut Institute for Resilience and Climate Adaptation (CIRCA), University of Connecticut
james.odonnell@uconn.edu

Steven Ruberg
National Oceanic and Atmospheric Administration’s Great Lakes Environmental Research Laboratory
steve.ruberg@noaa.gov

Christopher Sabine
University of Hawaii at Manoa
csabine@hawaii.edu

James Todd
NOAA Office of Oceanic and Atmospheric Research
james.todd@noaa.gov

Ed Verhamme
LimnoTech
everhamme@limno.com

Ian D. Walsh
Sea-Bird Scientific
iwalsh@seabird.com

William Douglas (Doug) Wilson
Caribbean Wind LLC Oceanographic Consulting Baltimore
doug@coastaloceanobs.com

Neal Pettigrew
School of Marine Sciences, University of Maine
nealp@maine.edu

DOCUMENT REFERENCE

McManus MA, K Bailey, U Send, R Burt, JA Newton, D Schar, J Morrison, G Doucette, RJ Allee, C Berchok, S Buschang, R Butler, G Canonico Hyde, F Chavez, S Colbert, J Crawford, S Danielson, EP Dever, J Dorton, R Esteves, R Green, K Grissom, C Hall, C Harvey, C Janzen, S McArthur, BD Melzian, JB Mickett, T Mudge, FE Muller-Karger, AN Netburn, EM Nosal, J O'Donnell, J Quintrell, S Ruberg, C Sabine, M Tamburri, J Todd, E Verhamme, ID Walsh, WD Wilson. 2018. Alliance for Coastal Technologies Workshop Proceedings: National Coastal Ecosystem Moorings Workshop. University of Washington 20-21 March 2018. 42 pp.