Ocean Research Advisory Panel

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Biogeochemical Observing Technologies Subgroup

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ORAP Task:

Develop a report to offer an initial set of recommendations to the U.S. Ocean Policy Committee (OPC) about opportunities to leverage public-private partnerships to advance emerging marine biogeochemical observing technologies and advance national ocean science initiatives. The report will identify barriers and challenges as well as examples of technologies that are mature for investment.

Initial Approach to Address Task

Referencing the priorities identified in the Ocean Climate Action Plan, members of the ORAP BOT subgroup drew on their own expertise and their professional networks to gather information to develop an initial draft for discussion with the broader ORAP.

Key Emerging Marine Biogeochemical Technologies:

- Microfluidics Applications for Ocean Biogeochemistry
- Acoustics and Ultrasonic Technologies for Ocean Monitoring
- Autonomous Instruments for Arctic Observations
- Non-invasive Imaging from Unoccupied Aerial Systems
- Environmental DNA (eDNA)
- Advanced Sensors for Carbon Related Chemistry

Initial Approach to Address Task

Under each “Key Emerging Marine Biogeochemical Technology” the report will discuss:

- Current and Potential Technology Applications, and
- Technology, Market, and Industry Maturity Level

Jorge Corredor

Microfluidics Applications for Ocean Biogeochemistry

Initial Findings: lab-on-a-chip (LOC) - lab routines in a single device - Current and potential technology applications

- LOC, etched into a single polymer chip and derived from benchtop automated analytical technology, greatly reduces legacy complexity, volume and waste streams
- LOC, is best used for multi-step aqueous chemical analysis
- Instruments for analysis of inorganic nutrients (plant food), pH, alkalinity and iron are now available
- Application for observation and research in harsh ocean environments has been demonstrated

Organic/biochemical LOCs in development include:

Single-cell flow cytometry to detect and discriminate phytoplankton
Phycotoxins
ATP
Colored Dissolved Organic Matter (CDOM)
Microplastics

Initial Findings: LOC technology, key innovators, market, and industry maturity level

LOC vastly reduces liquid volume, and complexity of legacy equipment while allowing faster reaction time, enhanced analytical sensitivity, portability, automation and parallelization

They may make way for large-scale sustained distributed *in situ* environmental sensors

- Few instruments are available on market
    - SBE briefly marketed an instrument for phosphate analysis but it was removed
- No US known commercial manufacturers; only Italy and UK
- Many ocean applications still to be developed
- Few buyers

Purnima Ratilal-Makris

Acoustics and Ultrasonic Technologies for Ocean Monitoring

Initial Findings: Acoustics and Ultrasonic…

Current and potential technology applications

- Acoustics/ultrasonics is the primary approach for remotely sensing vast regions of the ocean. Active imaging systems are used for depth echosounding, fish mapping, non-destructive testing, seafloor mapping, and underwater surveillance. Passive listening systems are used for ocean soundscaping, marine ecosystems characterizations, ship noise measurement and reduction, defense surveillance.

- To support a healthy blue economy, multi-scale ocean monitoring is essential. New opportunities include: (i) Wind farm 3D acoustic array sensor development with high SNR and real-time sensing, including localization and classification. Direct access to power from wind farms and data cabling to shore via buried fiber optic cables. (ii) Active acoustic/ultrasonic imaging systems development for rapidly sensing plastics pollution over wide areas of the water column

Initial Findings: Acoustics and Ultrasonic…
Technology, market, and industry maturity level

- Most passive listening systems comprise of single or small number of hydrophones, provide limited real-time sensing or localization capabilities. Large acoustic/ultrasonic array systems are primarily in the domain of large navies, are cost prohibitive and unaccessible.
- Needs: Wind farm monitoring acoustic array systems with enhanced SNR for 3D monitoring, including directional sensing and localizations in real-time for natural and anthropogenic sources, can include both active and passive sensing. Advances in instrumentation for pressurized ocean environments, innovations for controlled large bandwidth acoustic/ultrasonic sources/receivers, efficient power and amplification PCB designs, advances in combined software/hardware computing accelerations, statistical physics based signal and array processing applied to constrain machine learning, database management systems, Designs should focus on sustainable approaches and environmentally friendly solutions..

Danielle Dickson

Autonomous Instruments for Arctic Observations

Initial Findings: Autonomous Instruments for the Arctic

Current and potential technology applications

Seasonal sea ice cover and relatively shallow (~40-200 m) water depths in the U.S. Arctic limit the use of instruments like BGC-ARGO floats used elsewhere.

Moored instruments are vulnerable to ice scour and most are not capable of measuring in shallow depths. The data from moored instruments are generally not telemetered and are only retrieved once per year when the instruments are recovered.

Autonomous platforms can integrate sensors to estimate primary production or assess the community composition/abundance of phytoplankton, zooplankton, fishes, or marine mammals to provide information relevant to understanding the ecosystem (e.g., predator/prey interactions; harmful algal blooms; changes in biodiversity; forecasts for fisheries).

Initial Findings: Autonomous Instruments for the Arctic

Technology, market, and industry maturity level

Innovative technologies are under development that include: ice-responsive or ice-tethered profilers; tethered or autonomous underwater vehicles; air-deployed and ice-hardened assets (ALAMO floats, wave buoys); uncrewed surface vehicles (USV) that can operate in ice-free waters; and benthic camera systems.

These technologies are challenged by a limited market that makes investment difficult from an economic perspective. They would benefit from investment by those who seek to address Arctic or climate-relevant science and/or investors who recognize the opportunity to support equity and environmental justice by developing robust and cost-effective technologies that could allow Arctic communities to engage in science directly.

Maria Tzortziou

Non-invasive Imaging / Remote Sensing Monitoring of Coastal Hazards from Unoccupied Aerial Systems

Initial Findings: Non-invasive Imaging from UAS

Current and potential technology applications

Remote sensing observations from imaging optical (RGB, multi-sepctral, hyper-spectral) and thermal as well as lidar sensors on unoccupied aerial systems (UAS) allow for automated detection of physical, biogeochemical, and ecological processes with minimal to no disturbance of the ecosystem/habitat.

UAS enable the collection of very high-spatial and high-temporal resolution observations for a relatively low-cost compared to more traditional methods.

Potential technology applications, particularly through successful integration of low cost, high signal-to-noise ratio (SNR), hyper-spectral sensors, would include monitoring of biodiversity, water quality, carbon cycling, fisheries, and food security, impacts of coastal hazards (e.g., flooding, harmful algal blooms, oil spills), satellite product validation, and assessment of the environmental impacts (positive and negative) of CDR approaches.

Initial Findings: Non-invasive Imaging from UAS

Technology, Market, and Industry Maturity Level

There have been significant recent advances in sensor capabilities and an increasing availability of UAS to the oceanographic community.

The technology and human capital are available to develop innovative and cost-effective technologies, particularly for more advanced, more accurate (higher SNR), hyperspectral optical sensors, and integration of UAS in the oceanographic research fleet. Protocols for advanced correction algorithms and products should be developed. Beyond new sensor technology, big-data technology development (image processing, data storage, downloading, processing) is necessary to accelerate application of UAS to non-invasive monitoring of marine ecosystems and hazards

Danielle Dickson

Environmental DNA (eDNA)

Initial Findings: eDNA

Current and potential technology applications

eDNA technology is mature for monitoring changes in the presence/absence of species and changes in community composition and biodiversity over time. Quantitative methods allow assessment of changes in the relative abundance of species over time.

Sample collection using traditional ship-based methods is expensive and time intensive and technological advancements in autonomous sampling are needed.

Applications include monitoring changes in biodiversity from regional to global scales to monitor the influences of a changing climate, or at local scales to monitor the potential effects of industrial activities. The technology could be applied to provide similar relative abundance data for fish as traditional surveys that employ nets.

Initial Findings: eDNA
Technology, market, and industry maturity level

Laboratory-based eDNA tools, techniques, and methods are highly evolved, mature, and widely utilized across biotechnology and biopharma industries.

Opportunities exist to advance innovative and cost-effective technologies for non-laboratory use, including field portable sampler technologies and autonomous eDNA samplers that can be integrated into uncrewed platforms and moored observatories. Fully automated devices that support real-time reporting (sample in, data out) do not yet exist in the market; yet, the technology and human capital are available to develop such tools.

Initial Findings: eDNA
Technology, market, and industry maturity level

Multiple current and nascent markets exist for eDNA technology in the marine environment including detection of invasive species, population and migratory assessment of managed species, search and rescue, defense applications, and public health management. For example, as the offshore wind industry grows, moored systems with eDNA samplers would be capable of monitoring trends in biodiversity near wind farms to determine the extent to which they create artificial reefs that change community composition and over what geographic scale that is likely to occur. Similarly, eDNA technology can support proactive assessment of biodiversity to inform commercial fishing catch limits and geographic restrictions (e.g., any potential opening of the Arctic Ocean to commercial fishing).

Maria Tzortziou

Advanced Sensors for Carbon Related Chemistry

Initial Findings: Advanced Sensors for C-related chemistry

Current and potential technology applications

Monitoring of carbon chemistry in the marine environment is typically done by measuring two of the four primary variables (pH, pCO2, DIC, Alk) and calculating the rest. A handful of long-term monitoring sites have documented changes in carbon chemistry for 20+ years, documenting that changes in carbon chemistry parallel changes in atmospheric CO2.

In addition to monitoring marine climate change, these sensors are used in monitoring coastal acidification, ecosystem productivity, and in the future will be key in monitoring, reporting, and verification (MRV) of marine carbon dioxide removal (mCDR) and storage

Initial Findings: Advanced Sensors for C-related chemistry

Technology, market, and industry maturity level

- Currently two primary in situ pH sensors - Sunburst and Seabird
- One in situ pCO2 sensor (Sunburst) and one commonly use quasi-in situ technique (shower-head equilibrator)
- Currently no commercially available in situ DIC or Alkalinity sensors
- The PMEL MAPCO2 mooring are widely used, but not commercially available
- All of these technologies require a fair degree of technical expertise and ancillary data (e.g. T, S, etc)

Eunha Hoh

A new platform for marine environmental pollutant monitoring

Initial Findings: A new platform for marine environmental pollutant monitoring

Current and potential technology applications

Digital sample freezing platform: a platform for archiving mass spectral data for the retrospective suspect screening of thousands of environmental pollutants. It is termed Digital Sample Freezing Platform and incorporates all the recent developments in mass spectral screening methods within the NORMAN Network. In the workflow, raw mass spectral data are converted to "standardized format", then mass spectral and chromatographic information on thousands of peaks of each sample is extracted into Data Collection.

Templates. Digital archives differ from traditional environmental specimen banks by the fact that results from analysis of environmental samples are digitally frozen, instead of physical samples being stored in freezers. The 'digitally frozen samples' can be retrospectively screened for the presence of virtually any compound in future. This has been recently proposed and practiced for marine pollution management in Europe (Baltic sea, Black sea etc).

Initial Findings: A new platform for marine environmental pollutant monitoring

Technology, market, and industry maturity level

- Mass spectrometry technology available for total scanning/nontargeted analysis/suspect screening is present (multiple vendors in USA: Agilent, ThermoFisher, LECO, etc)
- Sample collection strategies and methods in ocean have to be developed (such as selection of representative organisms for ocean pollution and sample collection methods/storage in ocean)
- EPA has been actively pursuing development and implications of the nontargeted analysis based on mass spectrometry for their regulatory framework
- Nontargeted analysis framework is also pursued in other agencies and industries (i.e., chemical safety in food products and product quality controls for food products)
- Implication of the technology for digital platform is quite new, currently being pursued in ocean pollution monitoring in Europe (in academia)
- Standardization for data format/storage is essential.

Challenges and Barriers to Public-Private Partnerships

Challenges and Barriers to Public-Private Partnerships

Anticipated Market

For many developing marine technologies, well defined use cases supported by a well defined regulatory environment are essential to allow for the evolution of technology development from exploratory research and development to wide-scale market adoption and industry engagement.

In situations where the regulatory environment supports the development and adoption of novel technologies, interagency coordination and alignment is essential to support the predictable and scalable market landscape industry looks to serve. Absent federal, state, and tribal interagency coordination on defined and accepted use cases for technology, market maturation can be severely constrained.

Challenges and Barriers to Public-Private Partnerships

Partnership Mechanisms

Development of new partnerships is often hindered by:

- Lack of awareness of potential funding mechanisms.
- Focused funding that provides limited financial support.
- Overwhelming paperwork needed to both apply for and receive federal funding.
- Delays in processing awards once funded
- General lack of support in developing public/private partnerships beyond a request for proposals/award.

These barriers persist throughout all levels of federal funding and discourages private and industry patterns from the committed longer-term development that is often needed to bring new technologies to fruition.

Tommy Moore

Challenges and Barriers to Public-Private Partnerships

Access to Technology and Equity Considerations

Access to technology has been a long-standing equity issue, particularly for communities that are lacking in financial resources or technical capacity. At present, this issue is being compounded by supply side limitations instrumentation (e.g. pH sensors) and backlogs in servicing and calibration of instruments. When partnering with the private sector agencies should consider:

- The diversity of communities who are engaged in priority setting, decision making, and are being funded.
- Access to the results of federally funded research. It is important for private organizations to be able to develop a market for a product or service, but this needs to be balanced with considerations of those who may not be able afford them.

Possible Recommendation for discussion: Addressing Challenges and Barriers to Public-Private Partnerships

Convenings

Agencies should consider:

- Providing more (and widely advertised) opportunities for the private industry (especially small companies and start-ups) to interact with agencies and the larger ocean community, to get feedback on needs and high-priority for science and technology (e.g., through focused workshops, targeted conference sessions, social media, other communication platforms).
- Facilitate discussions/interactions with all stakeholders at the table
- More funding opportunities for public-private-partnerships; opportunities at regular funding cycles to ensure development of long-term, sustainable technology-development programs

Possible Recommendation for discussion: Addressing Challenges and Barriers to Public-Private Partnerships

Communicating About Partnership Mechanisms and Funding Opportunities

- Enrollment in scientific societies provides support to researchers
- Attendance at meetings, local, national, and international, leads to personal relationships within science, industry and potential donor agencies
- Enhancement of such tripartite (industry, academia and administration) initiatives through widely targeted and widely disseminated funding opportunities is desirable

Possible Recommendation for discussion: Addressing Challenges and Barriers to Public-Private Partnerships

Cooperative Research & Development Agreements

Agencies should consider including in Cooperative Research and Development Agreements (CRADA) language that ensures that technology developed via public-private partnerships that then becomes the property of private investors can be verified, validated, and reproduced by the broader scientific community to ensure that the information these technologies generate is accurate and precise.

NEXT STEPS

- Seek the input of the broader ORAP on the direction of the subgroup.
- Continue to gather information and prepare a report by fall 2024.
- Consider inviting presentations to gather information related to specific topics as needed.