GOA-ON North American Hub Meeting Report

Hakai Institute 17-18 October 2017

The Global Ocean Acidification Observing Network (GOA-ON) Executive Council has encouraged grass-roots formation of regional hubs to foster communities of practice for the efficient collection, analysis and synthesis of comparable and geographically distributed data and models to assess ocean acidification and its effects, and to support development of adaptation tools such as model forecasts. As a result, the GOA-ON North American Hub was established in September 2017 to serve the ocean acidification community in Canada, Mexico, and the United States of America to support the development of synthesis products, support the observing system via training, develop uniform quality control procedures, and develop OA messages for policy makers and the general public, and established a Hub website (see http://www.goa-on.org/regional_hubs/north_america/about/introduction.php).

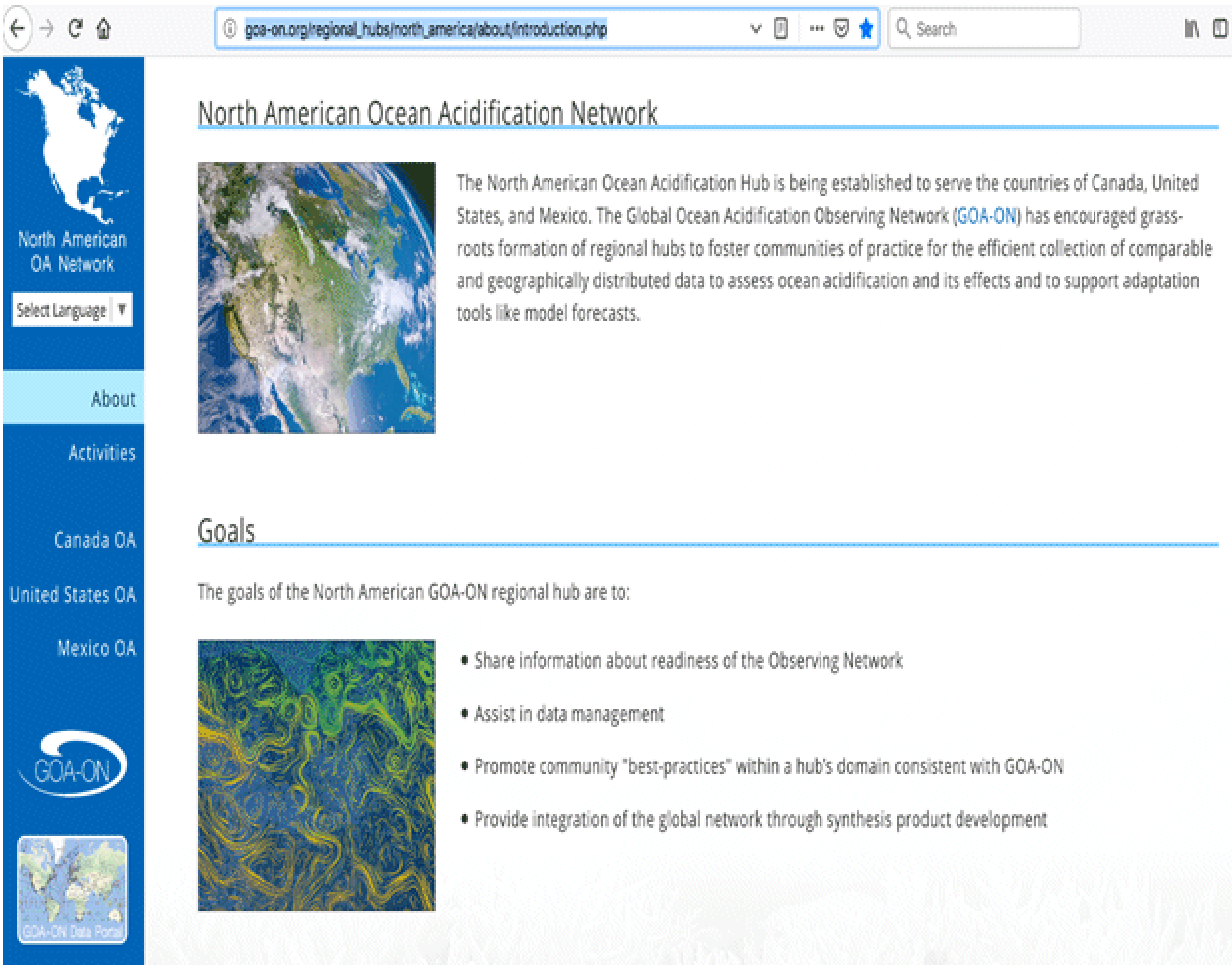

Figure 1. GOA-ON North American Hub Website.

1. GOA-ON Background and Goals

The Global Ocean Acidification Observing Network (GOA-ON) was established in 2012 as an international partnership to:

1. **Document the status and progress of <u>ocean acidification</u>** in open-ocean, coastal, estuarine, and coral reef environments, specifically to *identify spatial patterns & temporal trends; document & assess variation to infer driving mechanisms; quantify rates of change*
2. **Understand the <u>impacts</u> of ocean acidification on diverse marine ecosystems and societies**, specifically to *measure biological responses to chemical changes; quantify rates of change & identify areas of vulnerability or resilience* and
3. **<u>Support forecasts</u> of ocean acidification conditions,** specifically to *provide spatially & temporally-resolved chemical & biological data to be used in developing models for societally-relevant analyses & projections*

To meet these three goals of GOA-ON, three international workshops of the scientific community have defined the rationale, design, and locations of components for an international ocean acidification observing network, taking into account existing activities; a minimum suite of measurement parameters; a strategy for data quality assurance and for data distribution; and the requirements for international program integration in a Requirements and Governance Plan (Newton et al., 2015). This Plan specifies that GOA-ON requires capacity for several facets of the observing system: physical infrastructure, operations and maintenance, data QA/QC, analytical and synthesis activities, and the globally distributed intellectual infrastructure to sustain this. The system must cover diverse ecosystem types, oceanic to coastal, and utilize various observing platforms. The Plan specifies two data quality objectives, climate and weather, to cover the two different types of questions researchers have with the required data quality needed to address these.

Ocean acidification is a global condition with local effects. We need sufficient data and understanding to develop predictive skills and early warning systems. This requires coverage at appropriate scales, nesting local observations within global context. A global approach is needed because processes are occurring at global scales; therefore, we need to go beyond local measurements and observe on global scales in order to understand OA and its drivers correctly. We need information and data products that can inform policy and the public with respect to global and local status of OA and implications for overall ecosystem health (status) of the planet. We need local through global scale observations in order to get either correct. This issue demands coordination, networked skill, and open analysis. The global scientific community is not homogenous with respect to these capacities. GOA-ON has employed several tactics to overcome this: 1) members have come together to establish regional communities of practice, or regional ‘hubs’, that allow members to network, share expertise, and increase visibility of these efforts, such as the North American Hub this workshop is about; 2) GOA-ON has worked with partners on training workshops, mostly in developing countries, and launched the Pier-2-Peer mentoring program; 3) GOA-ON developed a data portal, allowing members to input and view data, metadata, and develop synthesis products; and 4) GOA-ON has a website for access to news and events, relevant resources and documents, the data portal, and regional hub websites.

GOA-ON is recognized for its contributions on global and local scales, playing a role in supporting the UNESCO Sustainable Development Goal 14.3 on marine acidity, as well as illuminating local conditions for uses such as aquaculture. The establishment of the North American Hub of GOA-ON allows members in Canada, United States, and Mexico to come together to identify and prioritize their needs and opportunities for regional collaboration to maximize our efforts.

2. GOA-ON Regional Hubs

The five regional hubs enable geographically-specific coordination and expertise to address hub-specific needs and gaps in monitoring. The Hubs have representation on the GOA-ON Executive Council and follow GOA-ON best practices. The GOA-ON Secretariat provides liaison with the Hubs as follows:

- Ms. Alicia Cheripka, NOAA OA Program - LAOCA, North American Hub
- Dr. Katherina Schoo, IOC-UNESCO - WESTPAC, Northeast Atlantic Hub
- Ms. Marine Lebrec, IAEA OA International Coordination Centre (OA-ICC), OA-Africa, PI-TOA

3. Goals of the GOA-ON North American Regional Hub

The North American Hub members had two preliminary introductory meetings in September 2017 and February of 2018 which were focused on recommending goals for the Hub and the preparing the groundwork for the first face-to-face meeting hosted by the Hakai Institute in Victoria, British Columbia in October 2018. The face-to-face meeting was focused on defining the major goals and near- and long-term priorities for the Hub for the next decade. The group reviewed the national OA programs, discussed our present understanding of OA conditions and biological responses, and provided recommendations for synthesis products, data exchange, website development, training and mentoring, outreach and future workshops. The following is a summary of the Hub member deliberations and recommendations organized by topic to address the goals and priorities of the Hub.

The defined goals of the North American Hub are to:

1. **Assess the current readiness of the observing network.**
2. **Provide integration of the global network through synthesis product development.**
3. **Assist in data management and making data available, particularly by ensuring that all observation platforms are represented on the GOA-ON data portal.**
4. **Standardize best practices for measurement methods, as well as experimental and calibration protocols for the carbonate system, consistent with GOA-ON.**

5. **Encourage the implementation and maintenance of long-term time series for the carbonate system, biological, and ecological parameters where appropriate.**
6. **Build capacity of members of the network through training, technology transfer, and knowledge exchange (e.g. observation, experimentation, modeling, and synthesis).**
7. **Coordinate and communicate among global, regional, and local/national programs.**
8. **Evaluate OA trajectories and biological responses for different types of ecosystems (e.g. estuaries, coastal, open sea) under a variety of scenarios.**
9. **Develop a scientific outreach program including a regional acidification assessment to inform the communities, policymakers and other stakeholders (industry managers, foundation leaders) about ocean acidification.**

4. Ocean Acidification Program Activities by Country

4.1 United States Ocean NOAA Ocean Acidification Program Activities

NOAA's Ocean Acidification Program (OAP) was established in 2011 in direct compliance with the U.S. Federal Ocean Acidification Research and Monitoring Act (FOARAM). As a Congressionally mandated program within the agency, the OAP and the science it advances represents an important element in fulfilling the agency's mission. The program mission is to better prepare society to respond to ocean acidification by fostering interdisciplinary research, monitoring, forecasting, and community outreach engaged through both national and international partnerships. The OA-ICC and GOA-ON represent the key international partnerships with which the program is engaged. In addition to the establishment of the OAP, the FOARAM Act called for the establishment of an interagency working group (IWG-OA) to coordinate the U.S. government (USG) response to ocean acidification. This IWG-OA is chaired

Figure 2. Group photo of the participants at the GOA-ON North American Hub meeting at the Hakai Institute in Victoria, British Columbia 17-18 October 2018.

by NOAA and vice chaired by the National Science Foundation (NSF) and the National Aeronautics and Space Administration (NASA) and includes additional representatives from the, Bureau of Indian Affairs (BIA), Bureau of Ocean Energy Management (BOEM), Department of Agriculture (USDA), Department of State (DOS), Environmental Protection Agency (EPA), Fish and Wildlife Service (USFWS), National Parks Service (NPS), Smithsonian Institution (SI), U.S. Geological Survey (USGS), U.S. Navy, and the Pacific Northwest National Laboratory of the U.S. Department of Energy. Bi-annual reports of all USG ocean acidification activities are available at https://oceanacidification.noaa.gov/_iwgoa/Documents.aspx.

This IWG-OA oversees the creation of U.S. Strategic Plan for Federal Research and Monitoring of Ocean Acidification which, together with NOAA's Ocean and Great Lakes Acidification Plan, guide the priorities and investment areas of the OAP. NOAA is currently in the process of refreshing its strategic plan and outputs form this workshop could prove useful in informing the international engagement elements of that plan. These and additional documentation are available here https://oceanacidification.noaa.gov/WhoWeAre.aspx . An overview of all of NOAA OAP's current and prior projects as well as their associated data and publications can be accessed at http://www.oceanacidification.noaa.gov/. The OAP science and monitoring portfolio is based around seven thematic areas: monitoring, technology, research, data management, modeling, social adaptation, and education. The bulk of the science portfolio is directed at assessing the potential vulnerability of the U.S. coastal Large Marine Ecosystems and U.S. affiliated coral reef ecosystems. To estimate vulnerability, the OAP works to engage transdisciplinary research to document environmental changes, assess the biological sensitivity, to such changes, and discern if/where these interactions could challenge human dimensions of the U.S. Blue Economy. This science is implemented in partnership with 15 organization across the agency includes at least seven laboratories, seven regional IOOS associations, eight cooperative institutes, and many academic institutions engaged through competitive opportunities.

The large proportion of OAP investment to date has centered on documenting OA conditions and trends within waters most relevant to impacted species under NOAA's purview (surface, subsurface, and near-shore). This National Ocean Acidification Observing Network (NOA-ON) is comprised of a portfolio of observing systems including Volunteer Observing Ships (VOS), biogeochemical surveys from NOAA research and fisheries vessels, and fixed autonomous buoys. Approximately 13 fixed MAPCO2 stations are supported through the NOAA OAP but these represent only a subset of the NOAA carbon observation network which has historically been supported through NOAA's Climate Program Office. The NOAA OAP stations are deployed in a broad range of habitats encompassing all the habitats of interest identified by GOA-ON from temperate coastal waters to coral reef ecosystems. Each station is charged with documenting diel dynamics in CO_2, air sea exchange, pH, T, S, O_2, Fluorescence, Turbidity, and an established protocol for discrete validation sampling on a regular basis. A key limitation of this observing system to date is that the system was originally designed around quantifying carbon fluxes which does not, in most cases, include a subsurface observing capability. OAP is currently investing in technology development at NOAA PMEL to address this limitation and an important priority for NOAA OAP going forward with the fixed observing system will be to accommodate a subsurface observing capacity to selected station.

The OAP supports one synoptic biogeochemical survey along a U.S. coastal LME every year. These surveys include the East Coast Ocean Acidification (ECOA) cruise, Gulf of Mexico and East Coast Carbon Cruise (GOMECC), West Coast Ocean Acidification (WCOA) cruise, and the Gulf of Alaska Ocean Acidification (GAOA) cruise. In nearly all cases, these cruises extend beyond U.S. waters into both Canadian and Mexican coastal regions and frequently include international participants from each of these nations. The OAP is dedicated to preserving the continuity of these surveys for the foreseeable future as resources permit. In 2017, GOMECC was executed for the first time completely circumnavigating the entire Gulf of Mexico. This was followed by ECOA in 2018 which extended into the Bay of Fundy, around the southern tip of Nova Scotia, and north to the Scotian Line off Halifax. In 2019 GAOA is scheduled to be executed in the Gulf of Maine and Canadian participation and coordination is being activity sought. In 2020, the expectation is that WCOA will be reoccupied and hopefully will extend beyond U.S. waters. The cycle will than begin again starting in 2021 so we should work towards strategically coordinating how are nations can been leverage these opportunities.

NOAA OAP scientists are currently drafting a unified set of protocols and best practices for the measurements obtained during these surveys which currently adhere to GOA-ON requirements. In addition, we are actively considering how/which biological metrics can be included as a core element of these surveys. We welcome the thoughtful insights that the GOA-ON North American Hub might offer in support of this capacity.

The NOAA OAP also supports targeted the development, maintenance, and application of several experimental systems within multiple NOAA Fishery Science Centers specifically designed to interrogate a broad range of biological responses to ocean acidification. These centers engage an extensive portfolio of experiments prioritized around the respective centers regional focus. For example, the Alaska Fisheries Science Center advances research targeting Alaska King Crab species while the Northeast Fishery Science Center are now engaged in studies examining American Lobster and Atlantic Sea Scallop. In addition to species response experiments, these centers along with numerous academic partners are actively engaged in modeling food web effects and incorporating uncertainties in biological responses into bio-economic models. While considerable work remains, these biological response efforts have significantly matured in recent years and research has begun investigating genetic markers and adaptive potentials of some species. Increasingly these experiments are working to understand responses to multiple stressors and include natural variability into the experiments.

Understanding what OA may mean for coastal community dependent of aspects of the Blue Economy which may be impacted of OA is a central area of interest to the OAP. In an effort to facilitate an exchange of ideas between the science community and the local communities, the OAP as established regional Coastal Acidification Networks around the U.S. In most instances, these organizations are led by regional IOOS associations and include NOAA Sea Grant Extension Agents to facilitate dialog with local interest groups. The organizations represent and nexus of federal, state, local, and academic interest centered on the issue of ocean and coastal acidification. These organization help to inform our science investments priorities to ensure relevance to the community interest and also to aid us in development information and data synthesis tools which are best tailored to offer decision support. Development of OA products which best address decision support from local to international scope is an area of increased interest to the OAP and we anticipate emphasis in coming years on this assuming available resources permit.

4.2 Canada

MEOPAR Canadian OA Community of Practice

MEOPAR created a Canadian OA Community of Practice (CoP) to coordinate efforts across all sectors, disciplines, and regions to share expertise and data, identify pressing needs for OA research and knowledge, and to create a collaborative and supportive environment for groups affected by ocean acidification. The specific problems/tasks that this CoP will attempt to address include: (1) development of a catalogue of ongoing OA research and physical infrastructure in Canada; (2) development (or leverage of existing) data sharing networks and interoperability standards to ensure accessibility of OA data for researchers and stakeholders; (3) development of best practices for experiments, sample collection, and sensor deployment, particularly with respect to "citizen science" and stakeholder data gathering; (4) improvement of linkages between end-users, and creators of OA data/knowledge; (5) development of regional hubs for certain OA research activities. We now have a web presence on the OA information exchange, our steering committee is selected, and we are inviting potential members to join up.

As described above, one of our primary goals is to build a catalogue of Canadian OA research including:

<u>Atlantic Coast and Gulf of S. Lawrence</u>

-Doug Wallace's team has established a VOS ship, which supplies an offshore oil platform. It's instrumented with O_2, pCO_2, Chl, CTD. Two other ships are coming online soon.
-Seacycler is still working in the Labrador Sea.
-Helmuth Thomas has a CARIOCA buoy near Halifax, but it is currently out of the water, and its future is uncertain.
-Kumiko Azetsu-Scott maintains sampling lines/stations from Bedford Institute (Halifax)
-Pierre Pepin maintains sampling lines/stations from Northwest Atlantic Fisheries Centre (St. John's)
-Al Mucci (McGill University) has, for the last 15 years, maintained a research program in the St-Lawrence estuary, discovering and tracking the development of hypoxic and acidified bottom waters and their impact on sediment geochemistry. More recently, this group has carried out a study of temporal variations of surface-water pH and saturation state at the head of the

Laurentian Channel (near Tadoussac) where 4 different water masses mix (Mucci et al., Can. J. Fish. Aquat. Sci 75: 1128-1141, 2018), and recently published a 10-year compilation and analysis of surface-water pCO_2 in the Estuary. A similar study of the Saguenay Fjord was recently completed (manuscript in preparation).

Arctic:
-CCGS Amundsen has maintained measurements annually since 2003.
-Smaller coastal research vessels are now available out of Cambridge Bay and Hudson Bay.
-An air-sea CO_2 flux station has been established in the Northwest Passage to study CO_2 exchange in the presence of sea ice.
-Institute of Ocean Sciences (DFO) has been involved in many Arctic cruises, dating back to early 1970s.
-Ocean Networks Canada has built a cabled observatory in Cambridge Bay that provides near-shore measurements of pCO_2, pH, T, S, PAR and fluorescence

Pacific:
-Ocean Networks Canada has OA assets on BC Ferries (one Ferry with pCO_2, other ferries with CTD, Chl), and at their Barkley Canyon node (profiling pCO_2 sensor).
-The Hakai Institute maintains a number of continuous monitoring platforms in both Alaska and British Columbia (BC), including: shore-based Burke-o-Lator installations, a volunteer observing ship, a mooring and a cabled observatory. The Institute also conducts routine full water column oceanographic sampling at select stations in the northern Salish Sea and the central BC coast, and partners with larger oceanographic institutions as well as citizen science groups to collect addition ocean acidification datasets. Data from many continuous monitoring platforms are present on the GOA-ON data portal, with quality controlled records available through the institution's data portal.
-DFO has maintained high-quality carbon measurements along Line P since 1985; the project has been managed by Debby Ianson since 2017. The carbon sampling effort is being reduced by 33-40% due to lack of funds. Specifically, Stations P16 will not be sampled and duplicates at P26 (Station PAPA) will only be collected once per year.
-DFO collects coastal carbon data in partnership with MEOPAR and NSERC
- DFO funded one large cruise in 2010 with international participation.

4.3 Mexico

4.3.1 Baja California Coast:

- In Mexico, in addition to the anthropogenic absorption of CO_2, the changes of water masses move the chemistry along the coast of Baja California.
- Along the coastal region of Baja California particular emphasis will be given to sampling El Niño/La Niña conditions.
- Develop early warning systems in real time along our coasts and provide the aquaculture industry with real-time information for decision making.
- Ensure that data from IMECOCAL cruises can be used for integration with US West Coast cruises.
- Develop cruise plans for August-September 2019

4.3.2 Gulf of California

- Conduct cruises of opportunity with SEMAR (Secretaría de Marina), two times a year (about March and November).
- Conduct a cruise with CICIMAR for 2019 (PI Dra. Laura Sanchez). They will deploy an ARGO in a cyclonic gyre. Invited Scientists: Drs. Espinoza and Dr. Hernandez.
- Monitor two times a year the upwelling area north of Sinaloa inside de Gulf of Mexico. (PI Dra. Leticia Espinoza).
- Invitation to participate in the Rocoso Reef Project inside the Gulf of California.

4.3.3 Tropical Region

- The OMZ is a great opportunity issue for a tri-national collaborative effort, it´s is a natural laboratory.
- Cabo Corrientes to Acapulco cruise by UNAM using El Puma (April 2019, PI Dr. David Hernández Becerril). Invited: Dr. Espinoza.
- SEMAR (Secretaría de Marina) for the Tropical area. Invited: Dr. Sosa, Dr. Chapa.

5. Overview of biological responses to ocean acidification

This session featured a discussion of species sensitivities, biological metrics used in experimentation, distribution of species studies, requirements and considerations for a true understanding of the effects of ocean acidification on marine organisms, suggested inputs from field observations and potential opportunities for collaboration.

Overall, biological experimentation has shown that for the majority of species studied, there are negative effects of ocean acidification, with socio-economic considerations for those that are commercial species. Pacific examples include negative impacts on multiple shellfish, salmon, crab and prawn species as well as impacts on tuna, organisms lower in the food web (krill, pteropods, coccolithophores) and ecosystem engineers such as starfish. Atlantic examples included Atlantic species of cod and halibut, American lobster, multiple crab species, blue mussel, flatfish (skate, flounder), pelagics (herring) and groundfish (ocean pout). Ocean acidification is a relatively new field for biologists and a diversity of metrics are used in studies, combinations of which may depend on the research question, expertise of the scientist, and available infrastructure. Metrics utilized include: general (e.g. growth, survival), developmental, cellular and immune function, physiology and behavior. However, the information available on species sensitivities is incomplete and very uneven, which may be a function of the species importance (commercially or ecologically), experimental ease of use and funding priorities. In order to gain a full biological understanding of what species may be the ‘winners’ and ‘losers’ in an acidified ocean, the following should be considered; life stage sensitivities, multiple stressors (particularly warming and deoxygenation), species interactions (rather than extrapolating from single species to ecosystem effects), food quantity and quality. Ultimately, one of the goals of biological research is to develop accurate ecosystem models incorporating species vulnerabilities, to enable effective predictions on future ecosystem state and for resource management use (e.g. sustainable fisheries resources incorporating climate and fishing pressures). Case studies of biological research in the northern Pacific (krill in Puget Sound, Moore Foundation-Hakai oyster microbiome, MEOPAR ICAP), tropical Pacific (corals, Gulf of Tehuantepec) and Atlantic (lobster multigenerational studies) were presented.

Other biological considerations discussed included multiple stressors and potential interactive effects (Dungeness crab study used as an example), transgenerational impacts, phenotypic buffering and acclimation, adaptive potential, spatial variability within species and impacts of extreme events.

Discussions of indicator species priority settings included scale (regional implications for some species), transboundary influence (also for geographical gradients) and if more or less vulnerable species should be chosen. However there likely will be a suite of indicator species employed (both sessile and pelagic) depending on scientific needs to be addressed.

Needs of biologists from field observations included: regional data which takes into account carbonate and environmental variability to facilitate environmentally realistic scenarios; accurate data taken with best practices and easily accessible; long-term data to monitor daily, monthly, seasonal and inter-annual variability; carbonate data at different depths to examine vertical habitat; need to identify cause and effect processes to enable mechanistic understanding, and; more precise and non-invasive methods for field sampling. The Hakai chemistry-biology coupled shellfish fieldwork was used as an example of how to monitor real-time biological responses to changing environmental conditions using non-invasive techniques, paired with controlled laboratory manipulation studies to examine acclimation and adaptation.

Opportunities for tri-lateral collaboration and leveraging were also mentioned in this talk, from combining cruises, to use of experimental infrastructure, to utilizing samples from long-running programs such as the Continuous Plankton Recorder. Post-talk discussions included selection of indicator species, how to conduct experiments taking into account regional variabilities, and considerations for experiments using multiple species.

6. Biological effects of OA under field conditions: Moving towards an integrated bioassessments

Ocean acidification (OA) is happening at the interface of chemical, biological and human dimensions. While physical-chemical observation demonstrates unprecedented rates of chemical change, we have very limited understanding of the OA implications for human and ecological communities. This stems mainly from the poor understanding of short and long term biological responses and their time of emergence from which inference of significant decline beyond their natural variability would be possible. While the changes in carbonate chemistry can directly translate to the habitat suitability decline, the chemical observations alone can only provide indirect measure, and hence the inclusion of biological responses is absolutely needed for the interpretational benchmark. However, to evaluate biological vulnerability under the projected rate of the OA, an improved characterizations of the chemical-biological coupling is needed. This includes interpretation beyond the global averages, focusing on the regional changes with its dynamic variability in intensity, duration and frequency of exposure that can impact species and community tolerance ranges and thresholds under current and future projected conditions.

The abundance of data on the experimental biological responses is offset by the paucity of field data, *in situ* measurements under realistic exposure, especially from the diversity of species, their life stages, and endpoint responses that would allow connecting sub-lethal and population level responses. Even if long-term biological observations are available, they often do not include the appropriate carbon system parameters. Sensitive and robust OA biological indicators capable of revealing the state of ecosystem integrity are still missing, and there is no clear consensus on the biological measurements to be made. Combining field and laboratory experiments offers the opportunity to provide a mechanistic understanding of the correlations found in the natural environment, while coupling field biological data with modelling paves the way to accurate predictions. To be able to bring biological observations on track with the existing chemical data require an integrated bioassessment approach to link various components that are not sufficiently linked to date.

Here, we propose the following Bioassessment Hub objectives in the following priority order:

- An integration of biological and chemical data
- Strongly integrated field and experimental efforts for the mechanistic understanding
- Integration between field, monitoring and modelling efforts to provide comprehensive bioassessments that is comprised of the following:
- Essential components of the **biological field work** should identify and agree on studied taxa serving as sensitive and robust indicators, habitats they represent, relevant endpoints across various spatial and temporal scales (from cellular to physiological and population), develop best practice protocols and SOP for monitoring.
- **Synthesis work** should identify thresholds, agree on the integration of modelling and monitoring outputs to define realistic exposure envelope determined by the magnitude, duration and frequency of the exposure of either single or multiple stressors across different temporal and spatial scales.

Pteropods are an excellent example of an OA indicator species that has been extensively monitored for OA field response and integrated into bioassessment synthesis ranging from chemical to biological field observations, meta- and threshold analyses and modelling output. To span the range of possible impacts across both temporal and spatial scales, requires of OA responses studies using a variety of different biomarkers, including biomarkers of cellular stress and physiological impairments (calcification, shell dissolution) and lethality. Currently, we have several thresholds developed over different biological processes that allow for model output visualization of habitats at risk and refugia. By using different exposure metrics, intensity, duration and severity, thresholds can also be useful in spatial and temporal assessment of habitat decline or nutrient loading assessment.

OA often interacts with other stressors, providing various kinds of multiple stressors scenarios that impact species and community exposure outcomes and their vulnerability. Habitat suitability models produce indices (HIS) which are statistical models that define relationships between environmental conditions and species abundance capable of describing nonlinear (interactive) relationships between multiple stressors. Using chemical and biological data, supported by multi factorial experiments under laboratory conditions, we have successfully constructively HSI model for pteropods along the US West Coast to two interactive stressors (OA and warming) that can be used for predicting population level effects in the context of suitable habitat. Generated HSI can be used for a wide variety of conditions, organisms and models, allowing for extrapolation of chemical-biological data to field conditions in regions where local chemical and biological measurements are not fully developed, yet we can still construct HSI providing for multifaceted evaluation of biological responses.

7. Near- and Long-Term Priorities for the GOA-ON North American Hub

7.1 Goals of the GOA-ON North American Hub and GOA-ON Data Portal

- *Near-term*: Populate the North American Hub website (http://goa-on.org/regional_hubs/north_america/about/introduction.php).
- to include a directory, cruise coordination, develop a consensus on the hub name and a logo, etc.
- Develop the structure of the hub: form steering committee with individuals who take the lead on certain aspects of work (maintaining regular communications, ensuring annual (or less frequent) meetings, leading on engagement with stakeholders, leading on identifying opportunities for training, etc.)
- Provide annual reports to the GOA-ON Executive Council
- *Medium-term*: Make changes to the data portal so that it serves the needs of the hub; handshake with national data centers
- *Long-term*: Create a data synthesis paper to review state of the ocean acidification science across North American regions
- Develop a long-term strategy for CRMs, including freshwater and estuarine applications
- Encourage collaboration on investigating potential relationship between OA and HABs (particularly by tapping into citizen science HAB monitoring)
- Develop a data exchange platform on the North American Hub Website

- Create more data synthesis products to be featured on the portal
- Improve robustness of forecasts regionally
- Develop connections to other regional hubs; for example, through participation in training sessions

7.2 US OA Program

- *Near-term*: Coordination on upcoming cruises (ACOA in 2019, WCOA in 2020, other non-NOAA cruises), perhaps by creating a team on the OAIE about maximizing ship time sharing etc. Cruise Coordination approved by DFO-NOAA to fill gaps.
- *Medium-term*: Coordination around upcoming meetings and workshops (i.e. DFO-NOAA bilateral meeting in December, and workshop for coastal time series analyses to be held at UW)
- *Long-term*: Informing upcoming re-write of NOAA OA research plan

7.3 Canada OA Program

- *Near-term*: Create a comprehensive inventory of who's doing what in Canada
- Near-term: Ensure strategic plan for Canadian climate change program links with ocean

acidification

- *Medium-term*: Support development of new technology in the GOA-ON community and support empirical algorithm development; particularly in the Arctic
- *Long-term*: Create an inventory of how much emissions are being generated in the name of this research

7.4 Overview of Mexico OA Program

- *Near-term*: Coordinate for upcoming cruises along the west coast and upcoming work in the Gulf of Mexico in 2021, Gulf of California, and tropical Pacific.
- Share communications and journal access
- Add 3 buoys
- *Medium-term*: Support technology development, particularly technology that will be useful for the aquaculture industry (collaborate with work on ACDC, Cha Ba, and KC buoy)
- Implementation of student interchange
- Have periodical interactions via the internet, among subgroups in the hub with similar interests in OA.
- *Long-term*: International participation in proposals.
- Have a program for international exchange of students, technicians.
- Particípate in inter-calibration exercises
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7.5 Overview of Biological Responses to OA

- *Near-term*: Accurate chemical/physical monitoring data where organisms live to inform experimentation
- *Medium-term*: Facilitate opportunities and support for sharing infrastructure and joint projects on target species for experimentation (i.e. species that might be economically important and vulnerable, species that might be indicator species)
- *Long-term*: Develop multi-species vulnerability assessments for incorporation into models (i.e. for resource management)
- Develop more field programs integrating chemical, biological, and physical disciplines
- Technology development for combined chemical, biological, and physical observations (i.e. crab tagging project)

7.6 Development and Applicability of Indicators for Ocean Acidification

- *Near-term*: Combining chemical and biological observations for all work to develop indicators
- Develop plans for pelagic and benthic indicators we would want to use, which would vary by region and also by research question, and include indicators that encompass sublethal and lethal effects
- *Medium-term*: Develop Habitat Suitability Indices which incorporate multiple stressors for as many species and regions as possible, and develop Habitat Suitability maps that could be added to the GOA-ON portal
- Archive indicator species at the Smithsonian along with eDNA filters
- Identify spatial gradients of chemical and biological variables from which to derive biological thresholds

- *Long-term*: Integrating chemical and biological observations for modelling efforts to get to targeted policy products; while also improving modelling quality
- Evaluate model quality in terms of the mean and variability

7.7 Opportunities for Training and Best Practices

- *Near-term*: Participate in existing programs like Pier2Peer and training efforts
- Organize a workshop that would target people in North America in regions that are not as well represented (i.e. Arctic and Caribbean communities)
- *Medium-term*: Develop workshops to serve hub members on various levels (more advanced trainings and technology/methodology development)
- Encourage technology and knowledge transfer to regions with need for capacity
- *Long-term*: Develop workshops that encourage and train for citizen science involving both chemistry and biological responses (learn from Alutiiq Pride, Sitka, and Pacific Salmon Foundation examples), with particular use of e-learning and webinars (must also identify funding sources for such projects)
- Engage in efforts to increase awareness of OA among communities, industry, policymakers, etc.
- Support the development of accessible and low-cost equipment
- Encourage the development and use of remote sensing technology and the necessary algorithms
- Assessment of our capabilities for outreach with coastal communities

8. GOA-ON North American Hub Meeting Agenda

<u>Wednesday 17 October</u>

8:30 Welcome – Eric Peterson and Wiley Evans, Hakai Institute (20 Minutes)

8:50 Introduction and History – Richard Feely, PMEL/NOAA (10 Minutes) Charge: Address Goals of the Hub and Charge for the meeting. 1) Define our Mission Statement; 2) What is the readiness of the observing system and what are its strengths and weaknesses; 3) How can we improve data accessibility and data product development; and 4) What kinds of "best-practices" products would be most useful to the Hub?

9:00 Goals of the GOA-ON and GOA-ON Data Portal - Jan Newton, University of Washington (30 Minutes + 15 Minute discussion) Charge: Remind us on what are the Goals and Objectives of GOA-ON and how they relate to the GOA-On website and GOA-ON Data Portal.

9:45 Break (15 Minutes)

10:00 Other Regional Hub efforts – Meredith Kurz, NOAA OAP (30 Minutes + 30 Minute discussion) Charge: Provide an overview of other regional Hubs around the world; how are they organized and how do they function relative to GOA-ON.

11:00 Overview of US OA Program – Dwight Gledhill, NOAA OAP (30 Minute + 15 Minute discussion) Charge: Provide an overview of the US Ocean Acidification Program and provide examples of how it can best interface with Canada and Mexico. Can we have overlapping cruises in different years to provide more coverage? Can we share results and produce joint publications and data products? Can we share approaches for analyzing time-series data?

12:00 Lunch will be provided by Hakai Institute (60 minutes)

13:00 Overview of Canada OA Program – Brent Else, University of Calgary (45 Minute + 15 Minutes discussion) Charge: Provide an overview of the Canadian Ocean Acidification Program and provide examples of how it can best interface with the United States and Mexico networks. Can we have overlapping cruises in different years to provide more coverage? Can we share results and produce joint publications and data products?

14:00 Overview of Mexico OA Program – Martin Hernandez, Universidad Autonoma de Baja California (45 Minutes + 15 Minute discussion) Charge: Provide an overview of the Mexican Ocean Acidification Program and provide examples of how it can best interface with the United States and Canada networks. Can we have overlapping cruises in different years to provide more coverage? Can we share results and produce joint publications and data products?

15:00 Break (30 Minutes)

15:30 Overview of Biological Responses to OA – Helen Gurney-Smith, Fisheries and Oceans Canada (25 Minutes + 10 Minute discussion) Charge: Provide an overview of what we know about biological responses to ocean acidification and how we can enhance our field programs to address these responses.

16:05 Overview of Development and Applicability of indicators for Ocean Acidification – Nina Bednarsek, Southern California Coastal Water Research Project (25 Minutes + 10 Minute discussion) Charge: Provide an overview of what we know about the use of biological indicators and how we can use them to support field observations, modeling activities and management decisions.

16:40 North American Hub priorities - Discussion Leader: Richard Feely (20 Minutes + 20 Minute discussion) Charge: Discuss how what we have learned today can be utilized to address the major priorities of the North American Hub.

17:20 Adjourn for the day and Group Dinner (TBD)

Thursday 18 October

8:30 Opportunities for Training and Best Practices – Discussion Leader: Meredith Kurz, NOAA OAP (30 Minutes + 30 Minute discussion) Charge: Discuss how development of best practices and training events can be implemented to encourage collaboration among Hub members. What specific training requirements are being sought by the North American Hub community?

9:30 Opportunities for Collaboration – Discussion Leaders: Dwight Gledhill, NOAA OAP, Debby Ianson, DFO (30 Minutes + 15 Minute discussion) Charge: Discuss how cruise activities, training activities, and modeling can be enhanced to encourage collaboration among Hub members.

10:15 Morning Break (15 Minutes)

10:30 Data Exchanges and North American Hub Website - Discussion Leader: Jan Newton, University of Washington (30 Minutes + 30 Minute discussion) Charge: How can we facilitate data exchanges between the three countries? What synthesis products can we collaborate on?

11:30 Meeting Summary and Final discussion - Richard Feely - (30 Minute + 30 Minute discussion) Charge: Provide a summary of the meeting and define the next steps.

12:30 Adjourn

In Person Attendees

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