

Ocean Acidification Workshop II: Scoping the Approach and Priorities for Ocean Acidification Monitoring Activities in Alaska

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Table of Contents

1.0 Introduction to the Alaska Ocean Observing System	3
1.2 OA Workshop II – Scoping the Approach & Priorities for OA Monitoring in Alaska 3	
1.2.2 Goal.....	4
1.2.3 Objectives	4
2.0 Workshop Summary.....	4
2.1 Expand and Clarify the Recommendations of the Workshop I	4
2.1.1 Expand coastal OA monitoring to include additional moorings in most vulnerable regions.....	5
2.1.2 Provide real-time or near real-time OA parameters.....	11
2.1.3 Increase lab and field research on potential biological and “human use” impacts of OA	12
2.1.4 Identify breadth of species being studied for impacts by OA changes, with emphasis placed on lower trophic level prey sources for commercially important species first.....	14
2.2 Priorities for OA Monitoring in Alaska.....	14
2.3 Identify appropriate and acceptable technologies with respective goals for research and monitoring.....	16
2.4 Educate and build consensus on use of best practices for conducting OA activities..	21
2.5 Initiate a common and collaborative vision for OA activities in Alaska coastal waters	21
2.6 Establish an OA network for Alaska whose primary mission will be to engage with stakeholders and expand the understanding of OA processes and consequences in Alaska.....	21
APPENDIX A.....	23
List of Attendees.....	23
APPENDIX B	24
List of Presentation Topics.....	24
APPENDIX C	25
Detailed Meeting Notes.....	25

1.0 Introduction to the Alaska Ocean Observing System

The Alaska Ocean Observing System (AOOS) is one of 11 Regional Associations and represents the state of Alaska as part of the National Oceanographic and Atmospheric Administration (NOAA) Integrated Ocean Observing System (IOOS) Program to manage the statewide observing system. AOOS collaborates to build observing and forecasting capacity, delivers information to stakeholders and provides data management support to programs operating around the region. AOOS has three strategic priorities within its mission: 1) to sustain marine ecosystems and fisheries, and track climate change and trends; 2) to promote safe marine operations; and 3) to mitigate natural hazards and their impacts on coastal communities. It also represents a network of critical ocean and coastal observations and provides data and information products through its data assembly center (DAC) which utilizes advanced data portals and products that aid in understanding the status of Alaska's marine ecosystem. These data portals and products provide access to statewide data in one location, and assist stakeholders with making better decisions about their use of the marine environment.

AOOS owns and operates observing assets in the region, but frequently works with already established and ongoing projects to carefully balance the challenge of providing real-time observations in Alaska while using limited resources wisely. The mere size of the region alone requires extensive collaboration and leveraging of other programs to accomplish the AOOS mission. To augment these efforts, AOOS pursues additional funding opportunities, and offers data synthesis and management services to other organizations. AOOS supports monitoring and research across the state, and has been actively involved with supporting ocean acidification efforts in the region for nearly a decade.

1.2 OA Workshop II – Scoping the Approach & Priorities for OA Monitoring in Alaska

NOAA's ocean acidification research plan for Alaska (Sigler et al., 2015)) and some elements of the Arctic Research Plan (NOAA, 2015) outline objectives for OA research in Alaska and the Arctic region. However, there is currently no coordinated statewide, multi-agency plan/vision for monitoring OA in Alaska at the various temporal and spatial scales. AOOS, as a funding agent, receives requests to support OA monitoring activities ranging from instrumenting ferries and shellfish hatcheries to monitor OA, conducting shipboard surveys and collecting water samples, to adding OA sensors to existing moorings. Funding decisions for OA activities in the region would benefit from and result in more successful outcomes with a vetted OA monitoring guidance plan. As advances in OA sensing capabilities are occurring on rapid time scales and are promising new observing options over the next 3-5 years, emerging technologies along with established best practices for OA research and monitoring must be considered as part of this plan.

To kick-start a statewide OA planning objective, a second OA workshop was organized by AOOS to bring together technical experts and organizations actively engaged in OA monitoring and research around the region to share information on past efforts as well as current and future observing plans, and to discuss the necessary details, in particular sampling methods and approach, that should guide comprehensive long-term strategies and monitoring efforts in Alaska. Workshop discussion topics proceeded to identify and build consensus on OA observing priorities, acceptable standard operating protocols and best practices that utilize limited resources

most efficiently while producing high quality OA information for Alaska resource managers and researchers alike.

1.2.2 Goal

The primary goal of the 2016 OA scoping workshop was to initiate and provide guidance for planning and implementation of a cohesive and meaningful OA monitoring approach for Alaska, including establishing an OA network.

1.2.3 Objectives

- Expand and clarify the recommendations of the first workshop;
 - Identify priorities for OA monitoring in Alaska;
 - Distinguish appropriate and acceptable technologies that coincide with respective goals (e.g., short-term adaptive sampling activities vs. long-term monitoring for assessing trends);
 - Educate and build consensus on use of best practices for conducting OA activities;
 - Initiate a common and collaborative vision for OA activities in Alaskan coastal waters; and
 - Develop a plan for an OA network in Alaska, whose primary mission is to engage with stakeholders and expand the understanding of OA processes and consequences in Alaska.
- Priorities set forth by the network will further develop plans for implementing recommendations made during both workshops.

2.0 Workshop Summary

The invitation-only meeting was attended by 28 of 37 invited participants (Appendix A – List of Participants). Eight 10-20 minute presentations by regional and national experts in the field of ocean acidification research, monitoring and technologies were delivered to help guide discussions addressing the questions and topics of the workshop (Appendix B – List of Presentations). Presentation summaries, discussions and feedback relevant to workshop objectives and questions are provided in the detailed meeting notes (Appendix C). This report synthesizes the major findings of the workshop with respect to the workshop objectives. The still growing need to develop an understanding of baseline OA variability in Alaska waters was stressed throughout the workshop.

2.1 Expand and Clarify the Recommendations of the Workshop I

In December 2014, AOOS organized an ocean acidification (OA) working session in Anchorage following an informational ocean acidification workshop hosted by AOOS and partners (Alaska Center for Climate Assessment and Policy (ACCAP), Alaska Sea Grant, Alaska Marine Conservation Council (AK MCC), and UAF's Ocean Acidification Research Center (OARC)). The workshop provided a general overview of OA background information and existing conditions in Alaska, and how OA currently relates to Alaska marine ecosystems. Specific objectives of the working session were to define stakeholder needs for OA monitoring, research, education and outreach and to identify statewide action items. This first workshop and working session outlined a "Call to Action: Responding to Ocean Acidification in Alaska" (AOOS, 2014: <http://www.aos.org/wp-content/uploads/2012/02/OA-call-to-action-121714.pdf>), which posed next steps for better understanding the potential impacts of OA in Alaska. Four broad recommendations emerged in this effort:

1. Expand coastal OA monitoring to include additional moorings in most vulnerable regions, including the Bering and Chukchi Seas
2. Provide real-time or near real-time OA parameters

3. Increase lab and field research on potential biological and “human use” impacts of OA
4. Identify breadth of species being studied for impacts by OA changes, with emphasis placed on lower trophic level prey sources for commercially important species first

The first objective of the second OA workshop was to clarify and expand upon the recommendations proposed in the first OA Working Session.

2.1.1 Expand coastal OA monitoring to include additional moorings in most vulnerable regions.

Question 1: Where are mooring assets previously/currently/planned to be located?

Table 1. Details of moorings in Alaska that have historically, currently, or will measure OA parameters. (Please send changes/additions to this table to Janzen@aoos.org)

Basin	Principle Investigator	Location (lat/lon)	Instrumentation	Realtime Reporting	Sample Rate	Years in service
Gulf of Alaska	UAF Ocean Acidification Research Center (OARC)	Resurrection Bay 59.91N, -149.35W	Surface: MAPCO ₂ , Satlantic SeaFET pH, and SBE 16+ CTD (Temperature, Conductivity, Pressure) Subsurface (265m): SAMI pCO ₂ / pH, and SBE 16+ CTD	1/Day	3 hours	2011-present
	UAF-OARC	Southeast AK, Port Conclusion 56.26N, -134.67W	Surface: MAPCO ₂ pCO ₂ , pH, CTD 57.70°N, -152.31°W	1/Day	3 hours	2011-16
	UAF-OARC	Kodiak 57.70N, -152.31W	Surface: MAPCO ₂ pCO ₂ , pH, CTD	1/Day	3 hours	2011-16
	Sitka Marine Science Center and Sitka Tribe Collaboration	Near Sitka	TBD			2017?
Bering Sea	UAF Ocean Acidification Research Center (OARC)	Southeastern Bering Sea 56.87N/-164.06W	Surface: May-September MAPCO ₂ , Satlantic SeaFET pH, and SBE 16+ CTD Subsurface (67m): Year-round SAMI pCO ₂ (pH???), Satlantic SeaFET pH, and SBE 16+ CTD	1/Day	3 hours	2011-present
Chukchi Sea	UAF College of Ocean and Fisheries Science	NE Chukchi shelf, Southern Flank of Hanna Shoal 71.6N/-161.5W	Subsurface only (35m): Contros HydroC (pCO ₂), SBE SeapHOx (pH, dissolved oxygen, temperature, conductivity pressure)	NA		TBD 2016
Beaufort Sea	MARES Program, Bob Pickart, Woods Hole Oceanographic Institute	Eastern Beaufort	OA sensors will be installed on two MARES subsurface moorings in the Beaufort Sea (Arctic). Arctic moorings will only have subsurface sensors (SAMI pCO ₂ /pH).	NA		TBD 2016

TBD = To Be Deployed

Question 2: Exactly where are OA observing assets needed?

In NOAA's work plan for FY15-FY17 for OA monitoring in Alaska, ocean monitoring will continue. Two of four existing moorings deployed in 2011 will continue to be supported in the Gulf of Alaska and the Bering Sea (Table 1). Two of the existing Gulf of Alaska moorings will be discontinued in 2016 due to funding shortfalls. At the time of the workshop, no moored assets existed in the Chukchi and Beaufort Seas, and the southern Gulf of Alaska was about to lose one. As demonstrated in Table 1, there are plans to deploy moored OA instrumentation in all three of these observing gap regions. The Chukchi Sea OA sensors will be co-deployed at a planned long-term ecosystem mooring array near Hannah Shoal, a biological hotspot in the Arctic (<https://www.uaf.edu/cfos/research/projects/ne-chukchi-sea-moored-eco/>). Two new moorings, which may both include OA instruments, will be deployed in the eastern Beaufort in 2016, though details of exactly what was to be deployed was not available at the time of the workshop.

Question 3: How long should these moorings be in place?

The length of time a mooring should be left in one location depends on the purpose of the mooring. The following time-frames were discussed for various levels of monitoring objectives:

- Long-term trends: Minimum sampling should occur once per year for 10 years, or more often. For minimal sampling capacity, fall months are currently considered the best time of year to sample due to quiescent OA drivers during this time of the year.
- Seasonal variability: Sampling should occur monthly to weekly throughout the year, or more often when possible.
- Short-term variability: Sampling should occur frequently enough to resolve the semi-diurnal tide (every 6 hours) or more often; sample rate should occur at the Nyquist frequency (twice the highest frequency present in the signal, the minimum rate at which a signal can be sampled without introducing errors).
- Event or process studies: Sample at a high enough frequency for duration of the event or process period to examine the dynamics in question (e.g., incubation period for larval impact studies).

In terms of observing with moorings or other methods, the benefits of staying in a single location where a long-term OA record exists versus the benefits of moving a long-term monitoring effort(s) to another location to improve spatial coverage was questioned. In any given location or region, a long-time series is required to differentiate the short-term variability (events, seasonal, interannual) from the longer-term variability (longer term climatic variations). It is desirable to have decades, due to decadal variability in the climate. At a minimum, 10 years emerged in workshop discussions as the recommended minimal period necessary to identify a quantifiable trend that can be differentiated from seasonal and interannual variations.

The suggestion was made it may be suitable to relocate resources after 10 years; however, it was stressed that the original location will need to be revisited periodically due to increasing CO₂ in the atmosphere (and hence CO₂ exchange with the surface ocean), and the ever-changing freshwater inputs into the coastal ocean and the North

Pacific, especially in and around Alaska. Freshwater is expected to vary significantly with a warming climate, and is a contributing factor to variability in OA measurements. In Alaska, projections are for larger discharges due to glacial melt and increased rain fall in the Gulf, whereas other regions are projected to experience reduced precipitation and decreasing discharge as well as reduced fast-ice seasons. These factors all affect OA parameters as well as other ecosystem conditions, which also require long-term monitoring in order to understand trends in those parameters. Once the shorter-term variations are better constrained, relocating resources maybe more palatable, as long-term trends are occurring on longer time scales (decades) and maybe captured by less frequent measurements.

The Arctic may pose the most challenges in this respect, due to high inter-annual variability and constantly changing conditions, both short (seasonal to annual) and long-term (rapid changes from global warming), all superimposed on climate variations of similar length scales.

Question 4: What mooring methods make the most sense?

MAPCO2 sensors are currently being used by the highest quality moored installations (e.g., GAKOA and M2 moorings), but are restricted to surface moorings during ice free seasons. These moorings typically report near-real-time data. Real-time reporting of any subsurface instruments requires inductive modem capability. When real-time reporting is not available, subsurface instruments can log data that is uploaded when the mooring is serviced, which typically occurs one to two times a year.

Real-time observing is challenging in Alaska due to seasonal ice formation in many basins, in particular the Bering, Chukchi and Beaufort Seas. When moorings cannot be serviced prior to freeze-up, installation of surface buoys equipped with telemetry is not an option. This restricts real-time reporting of OA parameters to summer months only in basins where ice is present, though year-round near-real-time reporting is possible in the Gulf of Alaska, as occurs on GAKOA near Seward.

Question 5: What other observing approaches have been/are being implemented?

Sampling approaches are driven by the kind of data that are needed, which is usually constrained by the length and time scale of the processes of interest. Large scale OA variations require fewer and less frequent sampling, making a single mooring adequate if it samples often enough to resolve the tidal signal. Coastal areas exhibit much higher spatial and temporal variability, and require higher resolution sampling in space and time in order to comprehend the complexity and tease out the long-term trend, which is a primary goal of OA monitoring. Process oriented studies, such as impacts on biology, may require even higher resolution sampling in both the lab and field. Therefore, the scale of the process of interest drives how measurements are made. Table 2 provides a generic overview of oceanographic and coastal spatial scales.

Table 2. General temporal and horizontal spatial variability for various marine regions. (Please send changes/additions to this table to Janzen@aoos.org)

Marine Region	Temporal Scale	Spatial Scale
Open Ocean	Years 3-6 months (seasonal)	100-1,000 km
Coastal Ocean	2-10 days (weather)	1-10 km

	Months (seasonal)	
Coast near glaciers	Months (seasonal)	10 m – 10 km
Coast near river runoff	2-10 days (weather) Days to weeks (events) Months (seasonal)	1 m – 10 km
Coast near industrial sources (e.g., pulp & paper mills)	Hours (events) to weeks Seasonal (based on industry)	1 m – 10 km

Shipboard Sampling:

NOAA Cruises: In NOAA’s FY15-FY17 work plan for OA monitoring in Alaska, survey cruises, which will sample at higher spatial resolutions along coastal transects, are scheduled to occur every four years. A survey occurred in the Gulf of Alaska in 2015, and a Bering Sea or Arctic cruise is planned for 2019.

The Seward Line: This historical long term monitoring transect has been routinely sampled for OA parameters since 2008, and prior to that, JGOFS (Joint Global Ocean Flux Study) funded OA along a portion of the line. High quality water sample measurements for OA are being made, allowing for empirical derivation of carbonate parameters and the development of OA water quality algorithms. As with moorings, the goal is to complete a long-term time series of OA measurements along this transect. Once 10 years are reached, it is possible OA sampling resources will be relocated; however, the plan would be to return to this historical transect to complete a survey every couple of years to document changing CO₂ and freshwater discharge impacts expected in the region. The Seward Line is currently sampled twice annually, in both spring and fall. After the 10-year time series record is accomplished, it may also be possible to constrain the long-term trend with reduced sampling stations and a reduction of when the stations are sampled, for example, sampling in the fall only. Sampling may be further reduced if it is determined that the GAKOA mooring data can sufficiently track changes represented along this transect, or a portion thereof. Analysis of each scenario will be necessary to consider how to proceed after the 10-year series is completed.

The GO-SHIP Program (<http://www.go-ship.org/>) - Global Ocean Ship-based Hydrographic Investigations Program: This decadal repeat hydrography program includes OA data collection along a subset of WOCE transects and other established lines. Sections relevant to the Gulf of Alaska included the N-S Pacific line from Antarctica to Kodiak, and the E-W line across the North Pacific. These cruises are planned on four-year cycles in order to capture changes on the decadal time scale, and they collect the highest quality (climate level) measurements. The results from this effort are aimed at estimating anthropogenic CO₂ signals while trying to determine how much it affects the CO₂ patterns.

Kachemak Bay National Estuary Research Reserve monthly water quality transects
The KBNERR conducts transects in upper Kachemak Bay and visits five transects quarterly in the outer Kachemak Bay and Lower Cook Inlet. These routine monitoring cruises added OA and marine plankton sampling efforts in 2011. Water samples are collected at all existing nutrient chemistry sites as part of the KBNERR routine monitoring effort for Kachemak Bay. OA water sample analysis has been performed at both OARC at UAF (Fairbanks) and at the Alutiiq Pride Shellfish Hatchery in Seward for carbonate chemistry. The goal of the KBNERR effort is to support and help direct

monitoring and research into the complex nature of ocean acidification in estuary habitats. Successful OA monitoring of these environments requires a higher temporal and spatial resolution sampling approach due to complex oceanographic and OA interactions.

World Ocean Circulation Experiments (WOCE): Some OA shipboard observing also occurred during the 1990-2002 WOCE efforts – World Ocean Circulation Experiment (<https://www.nodc.noaa.gov/woce/>) (see also these other data resources: <http://www.nodc.noaa.gov/woce/wdiu/> and the WOCE Atlas, <http://woceatlas.ucsd.edu/>).

Geochemical Ocean Section Study (GEOSECS): Work during the 1972-78 GEOSECS also included shipboard OA sampling (http://gcmd.nasa.gov/records/GCMD_CDIA_CNDP27.html).

Shore-based Sampling:

Alutiiq Pride Burke-O-Lator System (2014-present): The Alutiiq Pride Shellfish Hatchery in Seward in the northern Gulf of Alaska was the first shore-based installation to utilize a Burke-O-Lator system in Alaska. The Burke-O-Lator analyzes seawater for carbon dioxide partial pressure ($p\text{CO}_2$) and total dissolved inorganic carbon (TCO_2). Measurements of seawater temperature and salinity are also made in conjunction with the measured $p\text{CO}_2$ and TCO_2 . Using these four parameters, the saturation state of aragonite and pH are determined in real-time. Both the $p\text{CO}_2$ and TCO_2 measurements are made using non-dispersive infrared (NDIR) technology (LI-COR LI-840A). The Burke-O-Lator is operated as a continuous flow-through system and can also be used to analyze discrete water samples. Data from this effort are being used to develop a treatment system to test Alaska organisms' response to OA. <http://www.aaos.org/wp-content/uploads/2012/02/OA-call-to-action-121714.pdf>

OceansAlaska Burke-O-Lator System (August 2016 – present) OceansAlaska is located in Ketchikan, AK (Southeast Gulf of Alaska). See the Burke-O-Lator description above.

Both the Burke-O-Lator monitoring systems at Alutiiq Pride and OceansAlaska are part of the IOOS Pacific Region Ocean Acidification Network ([IPACOA](#)) that links seven similar sites across along the Pacific coast of North America.

Sitka Tribe Burke-O-Lator system: A new Burke-O-Lator system near Sitka is set to be installed sometime in 2017, but specifics were not available during the time of the workshop.

Shore-Based Water Sampling by community observers (2015-16): An active community-based program is funded by a Bureau of Indian Affairs (BIA) grant and includes participating villages: Chenega Bay, Eyak, Nanwalek, Port Graham, Seldovia, Seward, Tatitlek and Valdez. Water sample kits are supplied to villages and partners, and samples are taken once a week at the same place and same time (if possible) with the goal of continuous sampling for two years. Water samples are “grabbed” in a bucket or directly from the ocean into clean sampling bottles, then preserved and capped prior to shipping to Alutiiq Pride for discrete sample analysis in Seward using the Burke-O-Lator system. The goal of this program is to determine what the near-shore patterns are in carbonate chemistry for the two-year period of the study.

The Kachemak Bay National Estuary Research Reserve (KBNERR) shore-based water quality program (2016 - present). OA water samples are collected at all existing nutrient chemistry, shore-based sites as part of the KBNERR routine monitoring effort in Kachemak Bay. Water sample analysis is conducted at the Alutiiq Pride Shellfish Hatchery for carbonate chemistry.

Gliders and Autonomous Vehicles

MAPCO₂ sensors on surface dwelling gliders (e.g., *Liquid Robotics Wave Glider*) - *Summer of 2014*: A survey in the Gulf of Alaska was completed using two Liquid Robotics wave gliders equipped with a MAPCO₂ and a continuously recording CTD. Glider deployments have limited deployment mission lengths but can be left unattended for a few weeks or months, depending on the payload and sea state conditions. They offer an approach for gathering spatially resolved data without the use of a ship for prolonged periods of time, and are a proven tool in ocean observing efforts worldwide. The limitations are the ability of specific types of gliders to carry the necessary OA payload to render useful measurements. This methodology is still considered in the RnD stage. Gliders that are not surface dwelling (e.g., Slocum Gliders) are being tested to carry OA sensors but cannot accommodate surface MAPCO₂.

NOAA Arctic Research Program – new glider program. Future Arctic glider work is planned (summer 2016) with at least one wave glider - the same that was used in the 2014 Gulf of Alaska survey. A mooring will also be positioned on a seasonal (open water) basis to provide glider data validation. A second wave glider is proposed, but not certain at the time of the workshop.

NOAA SailDrone. NOAA is currently testing another surface dwelling autonomous vehicle called a SailDrone that can carry a significant payload and be left unattended for longer periods of time (sea trials have completed 97 days). This system currently has completed missions with an onboard CTD, but does not have the capacity to carry OA sensing technologies at this time. The SailDrone will be deployed for an Arctic sea trial, traversing the Northwest Passage to Hailifax, Nova Scotia over a five-month period in 2016-17 (without OA sensors). A future objective is to integrate OA sensors on this new platform for extended deployments in regions where shipboard observing is complicated or too costly.

Argo Program (2014-present). The Argo Program maintains a minimum of 3,000 autonomous profiling floats in the world's oceans, some with new pH sensors. The floats are programmed to complete a vertical profile from 2,000 dbars every ten days, and transmit their data via iridium satellite, making data available within a few days of retrieval. These floats started over a decade ago sampling only the core CTD parameters (T, C, P), but in recent years, have been expanding their biogeochemical sensor payloads to include DO, optical properties, nutrients, and now pH. MBARI in Monterey developed a pH sensor for the Argo Program, and these sensors are currently being developed commercially for high quality pH measurements for this program. This technology will naturally be transferred to other platform applications, such as in situ profiling moorings, gliders and traditional profiling from ships. This is an emerging technology which may become more palatable for Alaska in the future, as the ice continues to diminish, especially in Arctic waters.

Underway Shipboard Systems:

MApCO₂ systems are used on moorings, and are now being installed on tour boats, passenger ferries and container ships.

Transiting Container Ships. Up to 12 (not all in AK waters) container ships are currently equipped with MApCO₂ systems, including Horizon Container vessels that travel to and from Alaska.

Glacier Bay Tour Boat. A tour boat operating in Glacier Bay, Alaska had a smaller pCO₂ system installed similar to the MApCO₂, and successfully operated throughout the summer season of 2015, mapping OA parameters both spatially and temporally during the summer glacial melt cycle and demonstrating the role of glacial melt in the short-term OA signals and trends in these nearshore environments.

Alaska Marine Highway Ferry. Plans are in motion to install underway real-time surface mapping OA sensors (including pCO₂ and CTD-DO) on the M/V Columbia in the spring of 2017. The M/V Columbia travels along the entire coastline from Bellingham, Washington, past Vancouver Island, British Columbia, all the way to Skagway, Alaska. The ferry completes two passes to complete a roundtrip journey every week from May to late September.

2.1.2 Provide real-time or near real-time OA parameters

Question 1: Where should real-time (and non-real-time) OA data be collected?

Specific sites were not identified during this workshop; however, guidance for siting OA data collection efforts were discussed, and provide helpful distinctions for deciding where to deploy assets in the future. Many of these need to be considered together in order to decide if a given location makes sense in terms of OA sampling efforts:

- Locations where changes will have most impacts
- Locations that represent regional or basin area designations
- Locations where measurements have long historical records already
- Locations where likelihood of success at gathering long-term measurements exists (not too rough or hard to get to)
- Locations that can represent larger scale temporal variations (e.g., far from sources that might modify short-term and short-spatial variability)

It was noted that some areas expected to have high impacts from OA are nearshore, and the complexity of the OA dynamics in the near-shore will require higher resolution sampling in both space and time. High resolution temporal and spatial sampling will help decipher the inherent variability in these regions superimposed on the longer-term climate induced trends in oceanic (larger basin scale) OA. The cost of such near-shore sampling efforts could be cost prohibitive for certain programs limited by funding, resources (e.g., equipment, manpower) or technical capacity and skill level of the team.

Questions 2: Why collect the data?

- Sub-questions: What kinds of activities should these data be suitable for (e.g., forecasting, planning shellfish and fish hatchery aquaculture, etc.)?

- Will data be used for ambient monitoring and long-term trend analysis as well, or specific now-casts?
- Is the accuracy need different for these different efforts?

Accuracy needs can vary depending on the purpose of the data. However, the consensus was that measurements should optimally have multiple purposes: “one measure, many uses.” It was also stressed that low quality pH measurements (accuracy > 0.01) and other low quality water quality measurements (e.g., practical salinity > 0.01) are not useful for ocean acidification research and monitoring, though they may serve other purposes (e.g., analysis of industrial or sewage outfall water quality conditions). For the point of OA monitoring and research efforts, it is important that methods used in OA-specific work be of the highest caliber in order to be useful. This is discussed further in Section 2.3 of this report, including the technologies that are currently used for different OA parameters (e.g., pH, pCO₂), the best practices for achieving reliable real-time OA data for short and long-term analysis, and necessary requirements to collect water samples use these technologies effectively (e.g., technical skill of staff, existence of validation methods, ability to measure multiple parameters).

2.1.3 Increase lab and field research on potential biological and “human use” impacts of OA

Question 1: Labs exist, but more money is needed to pay technical staff and researchers. Is it best to coordinate with other agencies or through proposal collaborations?

This question was not directly addressed, but could be a topic for an Alaska OA Network to take up. In discussion, it was noted that NOAA put together a work plan (Sigler et.al., 2015) for the regions and submitted it to the NOAA Ocean Acidification Program office (OAP) who reviewed it and allocated resources based on need. This plan includes biological research for crab, fish and corals. The coral research will eventually shift to studying physiological effects of OA on corals in the lab.

Another activity underway in Alaska is aimed at installing monitoring systems in shellfish hatcheries. The first installation was put in the Alutiiq Pride Shellfish hatchery in Seward. A dosing system is planned for Alutiiq Pride to help remediate periods where OA conditions in the ambient waters would be detrimental to the hatchery activities. A second system is planned for installation in Ketchikan in the summer of 2016.

Dr. Amanda Kelley will join the OARC in June 2016 and she plans to build out and develop the biological impact program for the state.

Question 2: What species should be used to assess OA and how to choose which ones to study? (e.g., are there a few indicator species that can be used on all OA efforts?) Do we already know what organisms we can monitor in the field that could provide an early warning indicator of the biological impacts of OA for Alaska?

Pteropods:

Dissolution and calcification of pteropod (or other organism) shells would be useful indicators of present and future impacts. An example of an indicator product is a table of pteropod responses alongside aragonite saturation states related to their biological status. There are efforts underway to archive pteropod data, some documenting 20 years of pteropod sampling efforts. These historical data are showing a decrease in pteropod

abundance only during upwelling months. Other studies show many species of pteropods try to avoid acidic water.

An additional indicator species (not defined here) could be collected on cruises as an integrated impact measure. Studies that measure the length of submersion in the under saturated conditions would help develop information on how to use shell conditions to assess how long these conditions have existed for a studied region.

Commercially important fish and shellfish species:

Work is being done on commercial species, though it is challenging, time consuming, and largely restricted to laboratory experiments. Crabs constitute the biggest shellfish industry in the nation and have been the subject of OA studies in Alaska. Species include Red King, Blue King, and Golden King (snow crab). Studies are primarily in the lab, and have examined OA impacts of various life stages (mature, juvenile, larval, egg). Crabs and fish occupy various locations in the ocean during different life stages, which makes it difficult to know when and where OA problems might occur in the field. For example, Golden crabs can be as deep as 1,000m where waters can be very corrosive. Crabs already experience a wide range of OA conditions, so the question is how to narrow down the periods in corrosive waters and assess impacts at those times.

A set of specific indicators needs to be identified when setting up biological experiments. For example, if the impact of pH impact is the measure, it already has been shown that changes in pH affect a fish's ability to move oxygen across its gills. However, other parameters, such as temperature, are also at play in an organism's response to its overall environment. To illustrate what is being learned, Red King crab are shown to have smaller eggs, smaller embryos and larger yokes in decreased pH conditions. They grew, but did not always have enough food to maintain growth. There was increased calcification in larvae, and juvenile growth length and mass was reduced. Overall survival decreased with decreasing pH. For tanner crabs, long-term exposure is an issue meaning short-term studies do not work for this species. Northern rock sole appear to be sensitive to OA, with lower growth rates observed at high CO₂ levels. Each species responds differently, and selecting a single species will not translate to OA impacts to all, in other words.

It would be helpful for a biological field component to be added to monitoring efforts; however control samples or baseline data are first needed due to the significant variability in natural systems. Physical circulation changes will be important as this drives water quality conditions and will determine where recruitment occurs and larvae can survive. Ongoing work on understanding the physical environmental changes are still very important to this effort.

Prey (calcareous plankton):

Euphausiids are a critical species for all fisheries, and may be a good place to start with respect to biological sampling. Krill are being studied in Antarctica, and Pacific Krill could be another organism to sample alongside other oceanographic efforts.

Shelter organisms (Corals):

Red tree corals are ecologically important at 125-400 m (under ice glaciers in Alaska). They are found from Washington to the eastern Bering Sea and provide essential fish habitat for commercial fish. Recent minerology analysis indicates red tree corals are

made of a particularly soluble form of calcium carbonate, and are therefore at risk of physiological effects due to OA. Deep water corals are difficult to study in situ or by sampling in the field. Coral are currently being held in treatments at the NOAA Kodiak Laboratory where initial size has been recorded. The experiment is expected to run for months (until winter 2017).

Question 3: How do lab experiments reflect real-world conditions and how do we transition lessons learned in the lab to field experiments?

There is a need to expand studies to consider OA in a multiple stressor context. It is well understood that anthropogenic contributions of CO₂ is the major driver behind OA, but less is known about the combined roles of respiration, changes in temperature, dissolved oxygen and other variables. To understand the OA impacts on development of crab larvae, for example, understanding the ambient variability in the overall environment is needed before the impacts of the OA trends can be evaluated. Collecting crabs or other organisms during field studies in areas where ocean acidification is changing may shed light on their potential to acclimate and ultimately adapt. Identifying the best indicator species will vary by region.

2.1.4 Identify breadth of species being studied for impacts by OA changes, with emphasis placed on lower trophic level prey sources for commercially important species first.

Many species are being studied with respect to OA, but the scope of this workshop did not allow for an exhaustive compilation. Section 2.1.3 lists the organisms that were discussed during the workshop, with more details contained in the meeting notes and presentation materials from Richard Feely and Bob Foy. Developing an inventory of the species under study, what has been done, who is doing the work, and a bibliography should be a goal for an Alaska OA Network. A synoptic synthesis report that highlights major findings from lab and field studies for various species could then be used to help identify what specific organisms could be sampled in conjunction with other monitoring efforts.

2.2 Priorities for OA Monitoring in Alaska

The main challenge to OA monitoring and research in Alaska, as in the rest of the country, is the lack of adequate and dedicated funding. Priorities are many, but given the growing need to develop an understanding of baseline OA variability in Alaska waters, the following priorities emerged during discussion.

1. Make long-term observations to answer the following questions on a regional basis:

- a. *What is the regional change in OA?*
- b. *What is the natural variability in that region?* The signal is made up slow change (decades), annual variability, seasonal variability (months), and local external forcing events, which may also have seasonal time cycles unique to a region (wind stress, sea ice, glacial melt, primary production). The scales of variability need to be understood to tease out the long term signal, so again, this means collecting a long time series with frequent enough sampling to identify the shorter-term variability.
- c. *What are effects of external forcing and OA variability in regions?* (e.g., sea ice on OA in the Arctic; coastal upwelling)?

e. *What are the links between inshore and offshore OA conditions?* Alaska lacks the coastal resources and data to connect offshore to inshore OA conditions. Inshore sampling and evaluations require higher temporal and spatial sampling due to the inherent variability, necessitating a very coordinated and comprehensive approach. This will be costly, therefore a regional approach is likely more effective.

2. Identify / delineate regions in Alaska that can be used to form a regional approach to OA research and monitoring.

Regions should be identified, based on existing regional monitoring efforts (e.g., Distributed Biological Observatory (DBO)– Bering Sea through the Arctic) and new delineations as needed that identify ecosystem conditions or physical drivers specifically for OA variability. Examples: DBO; Marine Ecoregions of North America (Commission for Environmental Cooperation, 2009 - <http://www3.cec.org/islandora/en/item/3256-marine-ecoregions-north-america-en.pdf>). These regions may represent basin scales (e.g., more oceanic condition far from sources) or be highly localized regions of interest (e.g., estuary where shellfish grow operations occur). Collaboration and pooling of resources on a regional scale for regional assessments will also likely be the most cost effective way to tackle OA questions in Alaska, due merely to the size of the Alaska region.

3. Form regional alliances where resources can be pooled or leveraged to make effective OA observations.

Selection of regional breakdowns based on what is known, physical and biological details, risk or vulnerability, target species, etc. might be a good activity for the Alaska OA Network.

4. Develop appropriate OA indices where possible for the state by a basin scale and then a regional scale (to start).

5. Build an inventory of OA research on organisms in Alaska to help identify candidate (target) species for OA monitoring, and to help find effective ways to link OA with biology.

An inventory of organism response to changing OA would include species under study, who is doing the work and a bibliography. A synoptic synthesis report should then be prepared that highlights major findings from lab and field studies in order to help identify ways specific organisms could be used as target species on OA monitoring efforts.

Each region has different biological issues, and biology is affected by more than one environmental variable. Therefore, a field based biology co-sampling effort with identified target species would be based on an appropriate species that has had some laboratory work done to narrow down parameters. Sampling a target species combined with chemical and physical properties in various regions should be completed simultaneously and for long periods of time. To start, indicator species should be identified in locations where OA measurements are being made (e.g., pteropods can be used to assess responses and shell state conditions alongside aragonite saturation state of resident waters).

6. Secure the OARC function as a “Center of Excellence” to serve as a statewide resource to the OA observing community.

OARC at the University of Alaska has been the primary research hub for OA in Alaska, though with reduced state support, it may require new sources of income. The Alaska OA Network could provide resources for outreach to help train and educate Alaskans on best practices and OA field implementation protocols. This will also foster collaborations rather than having everybody working independently.

2.3 Identify appropriate and acceptable technologies with respective goals for research and monitoring

In order to identify the ocean acidification signal in the Alaska coastal waters, long-term measurements of OA parameters are needed on multiple temporal and spatial scales. Aragonite saturation is currently one of the best measures for assessing the state of OA for marine waters. Aragonite is a mineral form of calcium carbonate used by organisms to build protective shells. The saturation state of calcium carbonate as measured by the aragonite saturation level is used to determine if the chemical equilibrium in the water column tends towards dissolved or solid forms of the mineral. Lowered saturation states produce a dissolution condition that is capable of preventing shell formation on organisms or dissolving (eroding) existing shell structures. Aragonite saturation can be measured directly using water samples and laboratory analysis. Empirically derived aragonite saturation can also be determined using algorithms that relate the aragonite saturation to other OA parameters that are easier to measure.

The Global Ocean Acidification Network (GO-AN) Plan (2015) prescribes two quality levels for OA parameters to achieve meaningful results: “climate” and “weather” quality measurements. Both levels require competent laboratory analysis skills, and high accuracy, expensive instrumentation to achieve the accuracy described for each level. Table 3 lists the OA parameters and summarizes the method for measuring, accuracy capability of existing technologies and shows the accuracy needs based on the GO-AN initiative.

- “Climate” quality is the most discerning level for OA parameter measures, requiring high accuracy and precision. Climate level measurements are of quality sufficient to assess long-term trends. The defined level of confidence can detect long-term, anthropogenic-driven changes in hydrographic conditions and carbon chemistry over multi-decadal timescales. Such precision is currently achievable by a very limited number of laboratories and is not currently achievable for all parameters by even the best autonomous sensors.
- “Weather” quality is less discerning, yet still demanding strong quality assurance while making measurements with accurate and precise instrumentation. Weather level measurements are of quality sufficient to identify relative spatial patterns and short-term variations. The defined level of confidence should support mechanistic interpretation of ecosystem response to as well as impact on local, immediate OA dynamics. Though less stringent than climate quality data, weather quality data requires precision only achievable in well-trained, competent laboratories and with a select cohort of autonomous sensors.

The parameters required to make climate quality OA measurements include:

- Temperature (T), Conductivity (C), Pressure (P) - all required to derive practical salinity (S);
- Dissolved Oxygen (DO); and
- Four variables that constrain the carbon system relative to ocean acidification including pH, partial pressure of carbon dioxide (pCO₂), total alkalinity (TA), and dissolved inorganic carbon (DIC).

The physical, chemical and biological parameters that should be included in the Alaska OA observing system programs, when appropriate, include T, C, P, (to derive S), pCO₂, TCO₂, NO₂, and DO. All should be measured simultaneously at a given location for OA objectives. These

parameters may also allow for derivation of aragonite saturation algorithms. As mentioned, high quality pH measurements can be used in place of TCO₂ in the above list, but are less ideal.

Methods for making these measurements include collecting seawater samples for laboratory analyses and use of in situ instrumentation. Water samples are required to measure DIC and TA, while various sensors with a range of capability are available for measuring the other required parameters (Table 3).

Table 3. List of OA parameters, symbol, accuracy range, accuracy need for climate trend, required auxiliary parameters. (Please send changes/additions to this table to Janzen@aos.org)

OA Parameter	Symbol	Water sample Sensor Algorithm	Accuracy Range Capability	Accuracy Need Climate*	Accuracy Need Weather**	Required Auxiliary Parameters
pH	pH	Sensor	0.003 – 0.1	0.003	0.02	T, S, P
		Algorithm				T, S, DO
Partial pressure of carbon dioxide	pCO ₂	Sensor	0-2000 μ atm	0.5% uncertainty	2.5% uncertainty	T, S, P, DO
Total carbon dioxide	TCO ₂	Sensor				
Total dissolved inorganic carbon	DIC	Water		2 μ mol kg ⁻¹	10 μ mol kg ⁻¹	Direct Measure
Nitrogen Oxide	NO ₂	Sensor				T, S, P
		Water				
Dissolved Oxygen Concentration	DO	Sensor	0 – 120% surface saturation	1 μ mol kg ⁻¹		T, S, P
		Water				
Aragonite Saturation	Ω	Water				Direct measure
		Algorithm				T, S, DO
Total Alkalinity	TA	Water		2 μ mol kg ⁻¹	10 μ mol kg ⁻¹	Direct Measure
Temperature	T	Sensor	0.001-1	0.001	0.005	T, P
Conductivity	C	Sensor	0.0002 – 0.1	0.0002	0.005	T, P
Practical Salinity	S	Derived	0.002 – 1	0.002	0.01	T, C, P
		Water	0.002			
Pressure	P	Sensor	1-10 dbar depth dependent	< 3 dbar	.15% of full scale typical	T

The parameters pH and aragonite saturation can also be derived via commonly available software using algorithms derived from observational data relationships. For example, a program called CO₂SYS can use any two of the four measurable carbonate system parameters (TA, TCO₂, pH, and fugacity (fCO₂) or pCO₂) to calculate the other two, together with the inorganic carbon speciation and the saturation of calcite and aragonite. The program also allows the user to select from four different pH scales and several sets of dissociation constants widely cited in the literature.

The suite of observed parameters needed to develop empirically derived algorithms to estimate aragonite saturation include T, C, P, (derived S), pCO₂, TCO₂, NO₂, and DO, all measured simultaneously in one location. High quality pH measurements can be used in place of TCO₂ in above list, but are less ideal.

Development of empirical proxies to estimate pH and aragonite saturation using variables that are more easily and accurately measured (e.g., salinity, temperature, oxygen), shows promise for oceanic waters, but is more difficult to develop for estuarine, nearshore, and Arctic waters due to effects by other highly variable OA dependent factors (e.g., variability of freshwater inputs; algal bloom respiration events). The desired accuracy for observed parameters used in pH or aragonite saturation algorithms are summarized in Table 4.

Table 4. Accuracy objectives for observed parameters used in pH or aragonite saturation algorithms. (Please send changes/additions to this table to Janzen@aoos.org)

T - Temperature	0.001 deg C
C - Conductivity	0.0002 S/m
P - Pressure	3 dbar for full ocean depth (7K m)
S - Derived Practical Salinity	0.002
pCO ₂	
TCO ₂	
NO ₂	
DO	
pH	0.01

The OA parameter “pH” is measured on a logarithmic scale, hence small changes in pH mean large changes in acidity. This puts a discerning demand on ocean instrumentation in terms of initial static accuracy (factory calibration), calibration characterization (response of the sensor to multiple parameters such as temperature and pressure), calibration stability on the shelf and in deployment (including effects of fouling on measurement), and instrument performance characteristics (durability, service interval need). A select few technology developments are aimed at trying to achieve climate level pH accuracy, while some are already meeting weather level accuracy goals. Although sensor technologies are relatively mature for many parameters in Table 3 (T, C, P and DO), but as of 2014, commercially available sensors are only available for measuring the OA specific parameters pH and pCO₂ (GOA-ON, 2015), and NO₂ sensors are not mature technologies. Sensors for these parameters capable of measuring with high enough precision necessary to detect the ocean acidification signal are relatively expensive and require some skill to utilize correctly.

Tables 5 and 6 lists sensor technologies discussed during the workshop for measuring pH and pCO₂, respectively. (*NOTE: This table is not necessarily a complete listing, but it includes the sensors discussed most relevantly during this workshop.*) Not all of the sensors listed are available for purchase nor do they all meet the stringent accuracy requirements for climate and weather quality OA measurements. Factory specifications represent static accuracy defined by calibration capabilities in a laboratory, and do not always translate to realized accuracy experienced in the field. Realized accuracy at the time of, and after, deployment depends on use of best practices, durability of the technology and performance in variable environments (e.g., are sensors temperature-compensated and is the calibration of the sensor accounting for multiple

responses of the measurement (e.g., pH) to temperature, pressure, salinity and parameter (e.g., pH) gradients). Long-term stability relies on factors such as electronic or chemical drift and the effects of biofouling. Technologies continue to improve, and it is recommended the manufacturer's website be referred to for details on continued advancements in sensor capabilities.

Table 5. Available and emerging sensor technologies for measuring pH and factory specifications. (Please send changes/additions to this table to Janzen@aos.org)

Method (Brands)	Parameters	Range	Accuracy	Drift	Response Time	Application	Available Purchase
Traditional Glass Electrode Bulbs (YSI, HACH, Sea-Bird)	pH	0-14	0.1	high	1-90 secs Brand and temp-dependent	Hand held spot sample profiles	Yes Since 80s
In situ Spectrophotometry (SunBurst – SAMI and AFT)	pH or CO ₂	7-9 150-700 μ atm	0.003 (spec) 3 μ atm	 1 μ atm/6mos	3-5 mins	Best with salinity range 25-40 Moored T, S P dependent	Yes
Honeywell Durafet Technologies (ISFET – MBARI in Xprize) SeaFET, SeapHOx	pH	 6.5-9	0.02-0.03 0.02	0.003/mos 0.003/mos	Faster due to configuration on platform Slower due to configuration on platform	Profiling Argo floats Moored	 Yes
Optical Luminescence (Aanderaa)	pH		0.05	0.05/day @ pH=7 dt 1 min		Moored	Not Yet
Hybrid Bulb/Spectrophotometric	pH						Not Yet

Table 6. Commercially available instruments for measuring pCO₂ and factory specifications. (Please send changes/additions to this table to Janzen@aos.org)

Method (Brands)	Sample rate/cycle	Range	Accuracy	Drift	Response Time (1 tau, 63% final)	Application	Available Purchase
Burkolator						Laboratory	Special Order
PMEL/Battelle MAPCO ₂ (Licor-820)	20 mins					Mooring, Underway flow through	Yes
Kongsberg, Contros pCO ₂		200-1000 μ atm	\pm 1%	Not reported	1 min (with SBE 5 Temp)	profiling, underway gliders moorings laboratory	Yes

Sunburst SAMI pCO ₂		200-600 μatm	± 3 μatm	<1 μatm per 6 months	5 min	Mooring laboratory	Yes
Pro Oceanus, CO ₂ -Pro		0-2000 μatm	± 0.5%	Zero Drift onboard compensated	2.5 min	Profiling underway moorings laboratory	Yes

Since the accuracy of the data will define what it can be used for, the purpose should be well-defined in order to establish the appropriate accuracy need. It is best practice for data to have more than one purpose: “One measurement, many uses.”

Validation uncertainty (the error in the method or standard to which the sensors are being referenced) for pH using discrete bottle samples, as done during the XPrize, indicates an uncertainty in pH measurement close to 0.01 pH units in the upper 500 dbar (~500 m), and increasing linearly to 0.023 pH units at 3000 dbar. In other words, accuracies of pH < 0.01 are difficult to achieve. For the most exacting science, meeting accuracy requirements for pH will continue to be a struggle without improving the validation standard. It is impossible to ground truth a sensor capable of part per million (3 decimal place) measurements with a part per thousand (2 decimal place) accuracy standard.

Below is a summary of considerations before setting out to make OA specific observations:

- GO-AN reports two levels that are necessary for reporting data to their system: Climate and Weather. Both levels require laboratory analysis skills, and high accuracy, expensive instrumentation;
- pH should not be measured without other parameters. It is not useful on its own because a suite of variables is required to make use of pH data;
- pH values might not be accurate enough for developing aragonite saturation algorithms. Some sensors are not specified at high enough accuracies out of the box, while others may not perform well if not well maintained, calibrated or implemented appropriately;
- Accuracy requirements of both OA specific and auxiliary parameters is demanding and the competent skill level of the end user is imperative with most OA sensing technologies and laboratory work;
- Field observers should be skilled enough to learn or already know how to maintain and service instruments;
- Field observers must be trained on proper water sampling and preservation techniques;
- To determine whether to use expensive quality and reliable sensors, or perform a well-executed water sampling program, it is important to assess the end-user skill, amount of financial resource for the program, and sustainable capability. Water sampling is best suited for the unskilled practitioner, though training and careful sampling techniques are still necessary to make quality water samples used for OA analysis;
- Currently, only a select number of qualified OA laboratories should be used for sample analysis. It is important to budget for analysis of samples at a competent OA laboratory (both for measurements and sensor validation efforts);
- Sampling programs should have a carefully developed observing plan if including OA, and must consider sampling theory, which will define the spatial and temporal sampling resolution required to achieve necessary time series.
- Purpose of the data and accuracy goals (including how those goals will be achieved) should be well-defined before any sampling is initiated;

- Plans to make measurements from sensors installed on moving platforms must consider the sensor's response time to a change in the parameter being measured, the sample rate, the speed of platform, and the expected variability (gradients) to ensure quality data collection;
- OA sampling programs will need access to a skilled PI who understands the data, the errors inherent in data and capabilities and issues of the technologies. Even if this talent is not available in-house, having access for data review is beneficial. This is where the OA Network may benefit regional OA monitoring efforts.

2.4 Educate and build consensus on use of best practices for conducting OA activities

This workshop brought together OA experts and groups identified in Alaska who are currently conducting or planning OA monitoring activities. Not all those in the latter cohort are necessarily OA experts, and one of the goals of this workshop was to help bring the various expertise levels together to provide a crash-course on how OA research and monitoring should be conducted to achieve competent results. During the workshop, groups who were working independently or who were not aware of all the caveats in OA measuring were able to network with qualified experts and establish a better understanding on the processes of OA and how to monitor most effectively. Questions sent around prior to the workshop helped guide the discussion to help educate those new to the OA effort.

2.5 Initiate a common and collaborative vision for OA activities in Alaska coastal waters

Future efforts in Alaska would be well served by an OA Observing Build-out Plan. This was beyond the scope of this workshop, though many of the issues that need to be addressed were discussed and are outlined in this report. This will help guide the development of this plan.

2.6 Establish an OA network for Alaska whose primary mission will be to engage with stakeholders and expand the understanding of OA processes and consequences in Alaska.

The Alaska Ocean Acidification Network was established in June 2016. Its mission is:

- Engage with stakeholders to expand the understanding of OA processes and consequences in Alaska, and potential adaptation and mitigation actions. This will involve providing relevant information to, and hearing from, the fishing and aquaculture industries, policy makers, coastal communities and the general public.
- Work with scientists and stakeholder communities to identify knowledge gaps and information needs, and recommend regional priorities for monitoring, research & modeling in both the natural and social sciences.
- Share best practices for monitoring as well as promote the development of synthesis materials, and devise strategies to ensure funding is available to support these efforts.
- Promote data sharing and act as a resource hub for OA information in Alaska for researchers, stakeholders and the general public, leveraging the AOOS data portal as needed.

For more information on the AK OA Network, visit:

<http://www.aoot.org/alaska-ocean-acidification-network/>

Links to References Cited:

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<http://www.aooos.org/wp-content/uploads/2012/02/OA-call-to-action-121714.pdf>

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<https://www.iaea.org/ocean-acidification/act7/GOA-ON%202nd%20edition%20final.pdf>



Ocean Acidification Workshop II: Scoping the Approach and Priorities for Ocean Acidification Monitoring Activities in Alaska, January 29-30, 2016, Anchorage, Alaska.

APPENDIX A

List of Attendees

	Participant and Affiliation	Email	Attending (Y/N)
X	Matthew Baker (NPRB)	matthew.baker@nprb.org	Y
X	Lauren Bell (SSSC)	lbell@sitkascience.org	Y
X	Allison Bidlack (UAS & ACRC)	albidlack@uas.alaska.edu	Y
X	Richard Brenner (ADFG)	Richard.brenner@alaska.gov	Y
X	Shallin Busch (OAP, NOAA Fisheries)	shallin.busch@noaa.gov	Y
X	Rob Campbell (PWSSC)	rcampbell@pwssc.org	Y
	Tina Buxbaum (ACCAP)	tmbuxbaum@alaska.edu	N
X	Jess Cross (NOAA)	jncross@alaska.edu	Y
X	Seth Danielson (UAF)	sldanielson@alaska.edu	Y
X	Angela Doroff (NERRS)	adoroff@uaa.alaska.edu	Y
X	Darcy Dugan (AOOS)	dugan@aoos.org	Y
X	Wiley Evans (Hakai Institute)	wiley.evans@hakai.org	Y
X	Richard Feely (NOAA PMEL and OAP)	richard.a.feely@noaa.gov	Y
X	Robert Foy (NOAA AFCC Kodiak Lab)	Robert.foy@noaa.gov	Y
?	Burke Hales (OSU)	bhales@coas.oregonstate.edu	Webinar
X	Claudine Hauri (IARC – UAF)	chauri@alaska.edu	Y
X	Jeff Hettrick (Alutiiq Pride SH)	jjh@seward.net	Y
X	Kris Holderied (NOAA-Kachemak)	kris.holderied@noaa.gov	Y
X	Amy Holman	Amy.holman@noaa.gov	
	Chris Hunt (UNH)	chunt@unh.edu	N
X	Carol Janzen (AOOS)	Janzen@aoos.org	Y
	Libby Jewett (NOAA OAP)	libby.jewett@noaa.gov	N
X	Esther Kennedy (Sitka Tribe)	esther.kennedy@sitkatriben-sn.gov	Webinar
X	Holly Kent (AOOS)	kent@aoos.org	Y
	Will Koeppen (Axiom)	will@axiomdatascience.com	N
	Todd Martz (UCSD Scripps)	trmartz@ucsd.edu	N
X	Jeremy Mathis (NOAA ARP, CPO)	jtmathis@alaska.edu	Y
X	Sue Mauger (Cook Inletkeeper)	sue@inletkeeper.org	Y (Day 1)
X	Andrew McDonnell (UAF SFOS)	amcdonnell@alaska.edu	X
X	Molly McCammon (AOOS)	mccammon@aoos.org	Y
X	Natalie Monacci (UAF SFOS)	nmonacci@alaska.edu	Y
	Luc Mehl (Axiom)	luc@axiomdatascience.com	N
X	David Murphy (Sea-Bird Electronics)	dmurphy@seabird.com	Y
X	Jan Newton (NANOOS and UW-APL)	janewton@uw.edu	Y
X	Robert Seitz (MTS/IEEE Oceans 17)	rseitzak@aol.com	Y
X	Samantha Siedlecki	siedlesa@uw.edu	Webinar
	Sarah Trainor (ACCAP & IARC)	sarah.trainor@alaska.edu	N

(Please send changes/additions to this table to Janzen@aoos.org)

APPENDIX B

List of Presentation Topics

(Note: Titles may not match presentation slides)

Presenter	Topic	Link to presentation **
Jeremy Mathis, NOAA ARP, CPO)	Ocean Acidification Funding from FOARAM to the Future and Overview of NOAA, OAP, and NOAA's Alaska OA Research Plan (2015-17)	
Richard Feely, NOAA PMEL	The Ocean Acidification Signal in the Gulf of Alaska	
Bob Foy, NOAA Fisheries, Kodiak Lab	Overview on the OA Impacts on Biology	
Jessica Cross, NOAA CIFAR	Making OA Measurements in Alaska (and elsewhere)	
David Murphy, Sea-Bird Scientific	Review of pH Sensing Technologies, past and present	Carol has copy
Jan Newton, NANOOS, UW-APL	IPACOA Data Management Protocols and Using the GOA-ON Plan	
Shallin Busch, NOAA OAP	CAN (Coastal Acidification Network) Efforts in the Northeast and Southeast Regions of the USA, and what to think about for an Alaskan CAN effort	Carol has copy
Jeff Hettrick Alutiiq Pride Shellfish Hatchery	Overview of OA monitoring efforts at a that APSH	Carol has copy

****** To Presenters: *If you are willing to allow us to post your presentation, please email Darcy Dugan with permission, and send your power point presentation to her from this workshop if it is not noted above. We have some but not all of these presentations.*

(Please send changes/additions to this table to Janzen@aoos.org)

APPENDIX C
Detailed Meeting Notes

Ocean Acidification Workshop II: Scoping the Approach and Priorities for Ocean Acidification
Monitoring Activities in Alaska
January 29-30, 2016

<http://www.aaos.org/alaska-ocean-acidification-network/about/network-documents/>