SUCCESSES AND CHALLENGES OF INTERDISCIPLINARY OCEAN ACIDIFICATION RESEARCH IN ALASKA

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EXECUTIVE SUMMARY

Arctic regions are a bellwether for ocean acidification impacts, experiencing rapid and extensive onset of anthropogenically acidified conditions. Ocean acidification is already occurring in important commercial and subsistence fishery habitats and could have cascading economic consequences. In response to this risk, the Alaska Fisheries Science Center and the Pacific Marine Environmental Laboratory formed a novel partnership, the Alaska OA "Enterprise," to produce forecasting models of ocean acidification effects on fisheries and coastal communities from ocean observations, climate model predictions, and species response studies. This interdisciplinary scaled approach has been extremely successful in calculating and communicating potential economic risks and community vulnerabilities to decision makers. We highlight these successes to demonstrate the potential of this interdisciplinary framework to develop community research and monitoring priorities and build support for a sustainable long-term research program. Maturing Enterprise research along with extensive stakeholder feedback have co-identified future research objectives, including additional monitoring of spatiotemporal variability and experiments that assess long-term population acclimation potential and the roles of co-stressors for a wider portfolio of locally important species and populations. However, these emerging complexities represent a key challenge for future work: current resources cannot cover all observational scales and species of interest. To meet these needs, we emphasize that biogeochemical models, new observing technologies, and expanded partnerships may lead to new insights and meet the demand for actionable information on OA issues.

KEY WORDS

Ocean acidification; Alaska; Arctic; monitoring; modeling; forecasting; species-response; economic impacts; technology development; interdisciplinary collaboration

During the last decade, research has propelled ocean acidification (OA) to the forefront of the marine resources conversation in Alaska (e.g., Frisch et al., 2015). The progression of OA in this region has been faster than in many other ocean basins (Mathis et al., 2011a), and research shows that OA is already leading to some geochemical impacts in Alaska (Cross et al., 2013; Mathis et al., 2014). Of particular concern is that this anthropogenic perturbation could cause ecosystem-level shifts that diminish the overall economic value of commercial fisheries and reduce food security for communities that rely on subsistence harvests. Alaskan fisheries accounted for more than 60% of the catch by weight in U.S. fisheries with a first-wholesale value of approximately $4.2 billion USD in 2016 (Fissel et al., 2017), which created an estimated 99,000 full-time jobs and $12.8 billion in total output for the U.S. economy (McDowell Group, 2017). At this level, even a relatively small decline in one or more Alaskan fisheries could have cascading economic impacts for local communities, Alaska, and the U.S. as well as for trade with other nations.

Based on the potential risk to Alaskan fisheries and communities, the NOAA Alaska Fisheries Science Center, the NOAA Pacific Marine Environmental Laboratory, and regional universities proactively responded with baseline support from the NOAA Ocean Acidification Program (Sigler et al., 2008) to formalize a research initiative as the Alaska OA “Enterprise.” Understanding that the ultimate goal is to build resilience for local communities and the statewide economy to OA related changes, the Enterprise efficiently collects data and conducts experiments that directly support bioeconomic modeling of OA impacts, creating OA risk information that can be rapidly used by decision makers including local, state, and federal natural resource managers.

This novel partnership has produced a number of early achievements that support the business case for ocean observing in this region, the topic of this year's Arctic Observing Summit. For example, the Enterprise collaboratively produced a multi-faceted OA risk index for Alaskan communities (Mathis et al., 2015). Since publication, this information has been presented to a range of constituencies from school and community groups to the Alaska Governor's Office and the Alaska State Legislature. Larger communities with strong, diverse economies were predicted to be most resilient to OA, while smaller communities more dependent on marine resources for income and food security were predicted to be more vulnerable. This assessment sparked important and continuing conversations between stakeholders, decision makers, and researchers about how to build resilience against these risks.

Another key achievement was a targeted research initiative to assess the effects of OA on the economically critical red king crab fishery. Ocean biogeochemical observations (Mathis et al., 2011a, b; Cross et al., 2013; Evans et al., 2014) informed laboratory experiments that demonstrated altered embryo development and larval survival (Long et al., 2013b) and decreased juvenile growth and survival (Long et al., 2013a) under near-future OA scenarios. These results parameterized a population dynamics model to predict potential effects on fishery yield (Punt et al., 2014), which subsequently allowed quantification of the potential economic impacts in Alaska (Seung et al., 2015). By scaling the research up to the bioeconomic level, Seung et al. (2015) highlighted proactive fishery management adaptations which could minimize the economic impacts of OA. Specific actionable items included the need for ocean monitoring and more accurate spatially and temporally appropriate species-specific response data to support OA-related management decisions. This integrated research initiative was brought before the Alaska

Governor's Office Climate Leadership Task Force as critical evidence supporting investment in marine OA observing efforts.

Ongoing interactions among researchers and with stakeholder groups remain essential for the sustainability of the Enterprise. In 2016, a parallel effort by the U.S. Integrated Ocean Observing System led to the development of the Alaska Ocean Acidification Network (AOAN) specifically to connect scientists to community members, fishermen, and tribal leaders in Alaskan communities to share questions, needs, and concerns. By participating in AOAN, Enterprise members receive critical local knowledge and history as well as feedback from these communities that help inform research priorities and identify educational needs regarding the public understanding of environmental changes occurring in Alaska.

From the onset, it was recognized that the complexity and scope of Enterprise research would increase and expand over time. Species-specific sensitivity analyses continue to be critical for identifying the range of OA impacts (e.g., Hurst et al., 2013), but are recognizable oversimplifications of real world situations. With community and stakeholder support, current and planned research projects are exploring the interactions between OA and co-occurring stressors such as warming (Swiney et al., 2017), food web alterations (Hurst et al., 2017), and deoxygenation (Sigler et al., 2017). More complex response variables are being measured to consider cellular and molecular responses that lead to responses in macro-scale life history parameters studied previously (Meseck et al. 2016; Coffey et al. 2017; Sigler et al. 2017). Longer-duration experiments are being conducted to explore long-term sensitivity of vulnerable species and potential acclimation or adaptation capacity, a resilience that could substantially delay OA effects (Long et al., 2017).

However, critical gaps still remain. As an example, species need to be prioritized for response studies to include species that are important for local communities and keystone species that are bioindicators of ecosystem-level responses to OA. Researcher and stakeholder consensus has identified the need to understand the response of salmonids to OA because of their importance to local communities and ecosystems. This Alaska fishery sector is of critical importance to the food security of many small communities: annually, salmon represents 33% of the first wholesale value of commercial fisheries in Alaska, providing an estimated 32,900 jobs and over $5.9 billion to the U.S. economy (McDowell Group, 2017). To date, salmonid research has not been a focus of the Enterprise research portfolio. Expanding the Enterprise portfolio to include salmonid and other important species will depend on developing and leveraging new partnerships. Recently, the NOAA Ocean Acidification Program and the Department of Fisheries and Oceans Canada developed a collaborative framework on shared high-latitude OA objectives, which includes coordination of efforts between DFO and NOAA on monitoring, experimental research, modelling, and information sharing. Preliminary results from a knowledge gap analysis conducted by NOAA and DFO also pointed to the gap in salmonid research, further building researcher and stakeholder consensus around this new research priority that could drive new projects.

An additional gap identified by the Enterprise is the need to expand oceanographic monitoring to describe the dynamics of OA on the multiple spatial and temporal scales that drive biological systems. This is an enormous challenge in the vast, remote territory of Alaska: the Alaskan coastline is longer than the U.S. coastline along the East Coast, West Coast, Gulf of Mexico, and Great Lakes combined. Currently, our long-term monitoring assets are limited to two biogeochemical moorings and one quadrennial ship-based survey in the Gulf of Alaska.

While new technologies are expanding capacity for cost-effective OA observations in surface waters during the open water (ice-free) season, OA events are often most severe and sustained in sub-surface waters where many fishery species live.

To supplement this observing portfolio, the Enterprise is partnering with researchers in the Alaska Climate Integrated Modeling (A-CLIM) Project. Biogeochemical observations and species-specific sensitivities based on Enterprise and AOAN research are being used to validate a regional Bering Sea model that includes OA variables and simulations. This will create a powerful new tool that scales up Enterprise observations to predict OA conditions over a much broader territory, including at the sub-surface, and connects OA biogeochemistry to potential impacts across the Alaskan food web. The Enterprise is also exploring opportunities to partner with the National Marine Fisheries Service during their groundfish and crab population surveys in the Bering Sea. This would co-locate chemical measurements with a current, multi-decade time series of fisheries data. Such a collaboration could identify relationships between OA and fishery populations.

In summary, the early experience of the Enterprise includes several key lessons that may be of interest to the Arctic Observing community. The early successes of the Enterprise were predicated on a few critical components. Establishing and maintaining a focus on robust, peer-reviewed science provided confidence in the observations. Second, both biological and chemical observations were rapidly incorporated into tangible assessments that were accessible to the public fostering interest and collaboration across the state. The stable, multi-year funding mechanisms through NOAA’s OAP allowed the research to develop into the multi-layered biological and oceanographic observations used in these widely disseminated forecasting products. As OA science continues to mature, we look forward to building upon the established foundation to improve the assessment of ongoing OA in high latitudes. This will include developing sensitivity profiles for a wider suite of ecologically and economically critical species and generating forecasting products that meet local, state and federal policy-making needs. This will require continued engagement with multiple stakeholder groups to respond to emerging concerns within specific communities and industries. Addressing this increasing breadth of foci will only be possible with even greater partnerships that integrate efforts at the local, statewide, national, and international levels.

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