ACCESS NUMBER: **M08AX12760**

**STUDY TITLE:** Biogeochemical Assessment of the OCS Arctic Waters: Current Status and Vulnerability to Climate Change

**REPORT TITLE:** Biogeochemical Assessment of the OCS Arctic Waters: Current Status and Vulnerability to Climate Change : Technical Summary

CONTRACT NUMBER: M08AX12760

SPONSORING OCS REGION: Alaska

APPLICABLE PLANNING AREA: Beaufort Sea, Chukchi Sea, Bering Sea

FISCAL YEARS OF PROJECT FUNDING: FY 2008-2014

COMPLETION DATE OF REPORT: October 2014

COSTS BY FY: FY 2008: $ 490,021.00
FY 2009: $ 66,700.00
FY 2011: $ 199,983.00

CUMULATIVE PROJECT COST: $756,704.00

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**KEY WORDS:** Carbon dioxide, net community production, ocean acidification, Bering Sea, Chukchi Sea, Alaska outer continental shelf

**BACKGROUND:**

The Alaskan Outer Continental Shelf (OCS) is in the midst of several important environmental and social transformations, including climate-change pressures, increasing maritime traffic, and new exploration of offshore mineral deposits. In light of the major commercial fishing, trade, and energy resources potentially impacted by these changes, the Bureau of Ocean and Energy Management OCS Study AK-08-12-03 (Biogeochemical Assessment of the Outer Continental Shelf Arctic Waters) investigated the implications of two climate-change related processes on the carbon biogeochemistry of the North Aleutian Basin and the Chukchi Sea. This report quantifies the magnitude and fate of net community production (NCP), the primary energy source for secondary producers and higher trophic levels during 2008 and 2009. It also considers the response and vulnerability of the wider Alaskan OCS region to ocean acidification (OA), another manifestation of climate change. OA is caused by the buildup of anthropogenic $CO_2$ in ocean waters and increases carbonate mineral corrosivity. In naturally vulnerable areas like the Alaskan OCS, OA processes can cause substantial habitat stresses for marine organisms that build shells, skeletons, and tests from calcium carbonate, like several commercially important species in the Bering Sea.

**OBJECTIVES:**

Understand the relationship between the timing of ice retreat and the magnitude and fate of NCP by:

- Quantifying upper ocean net community production by measuring seasonal changes in the stock of inorganic carbon

- Employing elemental mass techniques to track the fate of NCP

Assess natural vulnerability of the Alaskan OSC to Ocean Acidification by:

- Better constraining understanding of the impacts of low-alkalinity ice melt, high $pCO_2$ river runoff, the remineralization of organic matter and the upwelling of deep Arctic basin waters onto the Bering, Chukchi, and Beaufort shelves on saturation state in the surface and bottom waters
- Developing regionally-specific algorithms to relate saturation states to standard hydrographic parameters for evaluation of trends in saturation states when full carbon system measurements are absent.

**DESCRIPTION:**

To investigate the implications of two climate-change related processes on the carbon biogeochemistry of the North Aleutian Basin and Chukchi Sea, we sampled dissolved inorganic carbon (DIC) and total alkalinity (TA) in the Bering and Chukchi Seas. The change in these parameters over time was used to quantify Net Community Production, the primary energy source fueling the Bering Sea ecosystem. These data were combined with simultaneously collected data from other projects to develop a carbon budget by elemental mass balance, which tracks the fate of this carbon through the base of the food web. DIC and TA concentrations were also used to calculate surface water $pCO_2$ and annual sea-air $CO_2$ flux, to determine how much carbon is returned to the atmosphere. Lastly, these DIC and TA samples were used to calculate pH and calcium carbonate saturation states, two key indicators of natural vulnerability to anthropogenic ocean acidification processes. We attempted to relate the natural spatial and temporal variability in these parameters to individual water masses and to other hydrographic parameters.

**STUDY RESULTS:**

Inter-annual and spatial variations in physical forcing exerted fundamental controls on the magnitude and fate of NCP, with cascading effects through the entire ecosystem. The two primary physical forces that impacted the magnitude and fate of NCP in the Bering Sea during 2008 and 2009 were the major hydrographic frontal systems that delineate the along-shelf domains and nutrient distributions in the Bering Sea, and the discharge of river waters into the Coastal Domain at the inner shelf.

In both the Bering and Chukchi seas, the primary control on ocean acidification and carbonate mineral saturation states was the biological pump, with phytoplankton utilization of $CO_2$ at the surface layer increasing pH and carbonate mineral saturation states ($\Omega$) and respiration processes causing the accumulation of $CO_2$ and subsequent suppression of pH and $\Omega$ in bottom waters. Other minor factors were also observed to contribute to variability in $\Omega$, including low-$\Omega$ river water. Sea-ice melt water was also found to exhibit low pH and $\Omega$, leading to carbonate mineral suppression at the surface layer. However, this effect was clearly overshadowed by primary production even in the Chukchi Sea, where ice melt and freshwater contributions were hypothesized to exert a greater control.

The data collected here did not find clear relationships between $\Omega$ and potential predictor variables like nitrate, salinity, and temperature. Some correlation was apparent between $\Omega$ and oxygen and between $\Omega$ and depth, but unfortunately not near the saturation horizon. A linearly additive conceptualization of the MLR model also did not reveal substantial predictive power of nitrate, oxygen, temperature, salinity, and depth to calculate saturation states.

**SIGNIFICANT CONCLUSIONS:**

Over the entire shelf, most NCP was found not to accumulate at the surface layer, indicating rapid heterotrophic utilization at the surface or rapid export. Three along-shelf domains differentiated by frontal features exist in the Bering Sea: the Coastal, Middle and Outer Domains. Export production studies

indicate that a higher proportion of NCP is exported to the benthos in the Middle Domain, where shallower depths and slow currents allow for highly efficient export. Of this exported carbon, more is also consumed by benthic communities than in the Outer Domain. By contrast, the Outer Domain exhibits a more pelagic character, with a greater fraction of NCP estimated to be assimilated by higher trophic levels at both the surface and in bottom waters. In this study, both wind and geostrophic transport exerted significant control on the fate of carbon, with approximately 30% of NCP lost to lateral transport in each domain. It is expected that pelagic energy pathways will strengthen for both regions with ice reduction.

These observations also showed widespread evidence that anthropogenic OA dramatically increases the intensity, spatial extent, and especially the duration of corrosive conditions over both the Bering and Chukchi shelves. Conditions potentially corrosive to carbonate minerals were observed in bottom waters over the shelf, where respiration processes are most prevalent. While river discharge and sea ice melt are typically lower in pH than ocean surface waters, primary production utilized $CO_2$ at the surface layer and resulted in very low corrosivity. In both the Bering and the Chukchi Sea, the contribution of anthropogenic $CO_2$ dramatically increased the severity, spatial extent, and duration of corrosive conditions over both the Bering and Chukchi shelves. Extremely severe conditions occurred in conjunction with signs of active carbonate mineral dissolution. These conditions were favored by strong respiration in relatively slow-moving waters, where geostrophic flows and tides did not extensively dilute respiration products.

**STUDY PRODUCTS:**

Data Products:

Stabeno, P.J., Sonnerup, R., Mordy, C.W., Whitledge, T.E., and Mathis, J.T., 3-21-2011a. HLY-08-02 CTD, Nutrient, and Carbon Data. Bering Sea Project Data Archive <http://data.eol.ucar.edu/codiac/dss/id=102.058>

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CDIAC submissions in progress, October 2014

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Mathis, J.T.*, and Questel, J.M. “The impacts of primary production and respiration on the marine charbonate system in the Western Arctic: Implications for $CO_2$ fluxes and Ocean Acidification. Fairweather Science Meeting, Anchorage, AK, 2013.

Cross, J.N.*. “Integrated assessment of the carbon budget in the southeastern Bering Sea: from the atmosphere to the sediment.” Alaska Marine Science Symposium, Anchorage, AK, 2013.

Cross, J.N.*, and Mathis, J.T. “Controls on carbonate mineral saturation states and ocean acidification on the Southeastern Bering Sea Shelf.” Third International Symposium on the Ocean in a High CO2 World, Monterey, CA, 2012.

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Cross, J.N.*, Mathis, J.T., and Bates, N.R. “Controls on Carbonate Mineral Saturation States and Ocean Acidification in the Southeastern Bering Sea.” American Geophysical Union Ocean Sciences Meeting, Salt Lake City, UT, 2012.

Cross, J.N.*, Mathis, J.T., and Bates, N.R. “Controls on Carbonate Mineral Saturation States and Ocean Acidification on the Southeastern Bering Sea Shelf.” North Pacific Marine Science Organization (PICES) ESSAS Ocean Sciences Meeting, Seattle, 2011.

Cross, J.N.*, Mathis, J.T., Bates, N.R., Moran, S.B., Lomas, M.W., and Stabeno, P.J. “The seasonal distribution of DIC and NCP on the Bering Sea Shelf.” American Geophysical Union Ocean Sciences Meeting, Portland, OR, 2010.

Posters at National and International Meetings:

Cross, J.N.*, and Mathis, J.T. “Ocean Acidification and Carbonate Mineral Saturation State Suppression in the Eastern Bering Sea.” Woods Hole Oceanographic Institution Ocean Carbon Biogeochemistry Workshop, Woods Hole, 2012.

Cross, J.N.*, and Mathis, J.T. “Nonconservative Variation of Total Alkalinity in the Subarctic Pacific (Southeastern Bering Sea Shelf).” Bering Sea Project Principle Investigator Meeting, Anchorage, AK, 2012.

Cross, J.N.*, Mathis, J.T., and Bates, N.R. “Controls on Carbonate Mineral Saturation States and Ocean Acidification on the Bering Sea Shelf.” Woods Hole Oceanographic Institution Ocean Carbon Biogeochemistry Workshop, Woods Hole, 2011.

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Local Presentations:

Cross, J.N.*, and Mathis, J.T. Carbon biogeochemistry of the eastern Bering Sea shelf: Mechanisms driving natural variability, anthropogenic perturbations, and some consequences for the ecosystem. Institute of Marine Science Departmental Seminar, Fairbanks, AK, 2013.

Mathis, J.T., and Cross, J.N.,* “Biogeochemical Assessment of the North Aleutian Basin Ecosystem: Current Status and Vulnerability to Change.” Coastal Marine Institute, Fairbanks, AK, 2012.

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Mathis, J.T., and Cross, J.N.* “Ocean Acidification: What it Means to Alaska.” School of Fisheries and Ocean Sciences Advisory Council, Fairbanks, AK, 2010.

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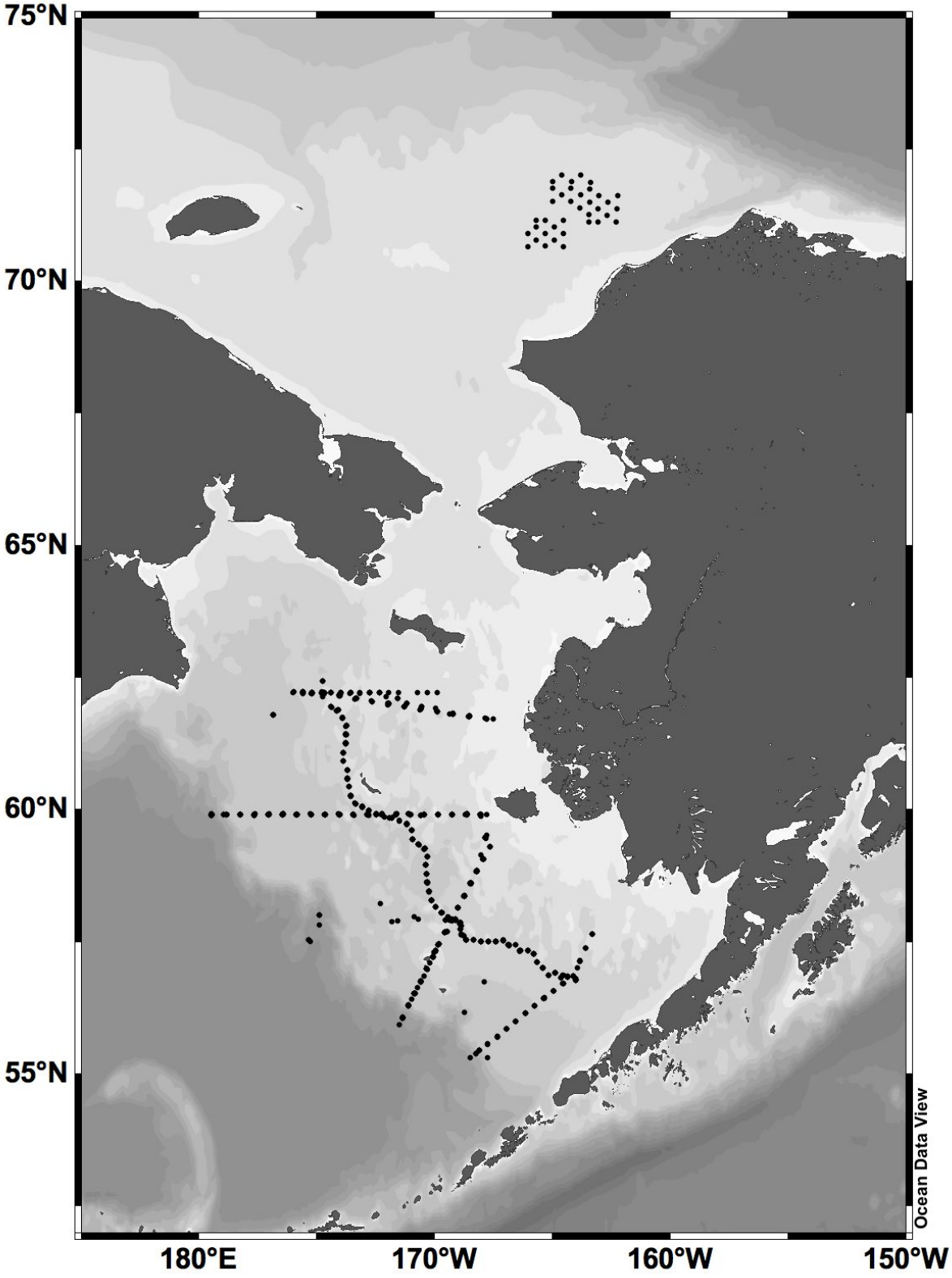
Map of Study Area: