



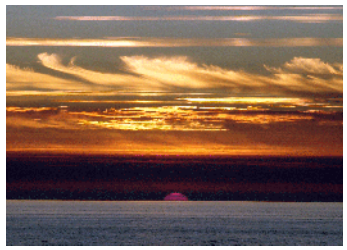



Final report on
CIFAR's shadow award NA08OAR4320870
RUSALCA: Russian–American Long-term Census of the Arctic

1 July 2008 – 30 June 2013

CIFAR
Cooperative Institute For Alaska Research

UAF
UNIVERSITY OF ALASKA FAIRBANKS

Final report from CIFAR to NOAA
on Shadow Award NA08OAR4320870

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RUSALCA
Russian–American Long-term
Census of the Arctic

Cooperative Institute for Alaska Research
P.O. Box 757740
University of Alaska Fairbanks
Fairbanks, AK 99775-7740
www.cifar.uaf.edu

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Cover photos were taken during the RUSALCA cruises in 2009, 2010, 2011 and 2012. All photos are by Aleksey Ostrovskiy except the one in the middle of the bottom row, which is by Bodil Bluhm.

Report layout and production by Barb Hameister, CIFAR.

CIFAR reports can be found on the Web at http://www.cifar.uaf.edu/research/reports.php

RUSALCA: Joint Russian–American Long-term Census of the Arctic research program in the Bering and Chukchi Seas—Final report for the period 1 July 2008 to 30 June 2013 for NA08OAR4320870

The Russian–American Long-term Census of the Arctic (RUSALCA), a joint U.S.–Russia research program in the Bering and Chukchi Seas, focuses on sampling and instrument deployment in both U.S. and Russian territorial waters and operates under the auspices of two Memoranda of Understanding between NOAA and, respectively, the Russian Academy of Sciences and Roshydromet. The RUSALCA objectives are to support NOAA's Climate Observation and Analysis Program and the Russian interagency Federal Target Program "World Ocean." It also provides some of the Arctic components of international and national climate observing systems including Global Earth Observation System of Systems (GEOSS), Global Climate Observing System (GCOS), and Integrated Ocean Observing System (IOOS). RUSALCA has also contributed to the U.S. interagency Study of Environmental Arctic Change (SEARCH) Program, NOAA's Office of Ocean Exploration and the Census of Marine Life (CoML).

The RUSALCA program is focused on gathering long-term observations towards understanding the causes and consequences of the reduction in sea ice cover in the northern Bering Sea and the Chukchi Sea in the Arctic Ocean. Models suggest that the expected changes in sea ice and albedo in this area will translate to significant alterations in water column structure and flow and in associated ecosystems. The program began in summer 2004 with a multi-disciplinary cruise on the R/V *Khromov*, a Russian ice-strengthened research ship, to investigate water column physics, nutrient chemistry, and pelagic and benthic biology. Oceanographic moorings were deployed in the western portion of the Bering Strait in 2004, and recovered and redeployed yearly except for in 2011. For 2007 and beyond, the RUSALCA program had planned an annual cruise focused on the physics in the Bering Strait region and more extensive multi-disciplinary cruises in 2009 and 2012 in the northern Bering and Chukchi Seas depending on resources.

Goals of the RUSALCA program

- Make physical, chemical, and ecological observations where Arctic sea ice is diminishing
- Monitor fresh water and nutrient fluxes via long-term moorings in Bering Strait
- Monitor ecosystem indicators of climate change
- Improve international Arctic science collaboration
- Explore the unknown Arctic

RUSALCA projects directly address two of the Cooperative Institute for Alaska Research (CIFAR) research themes, specifically,

1. **Ecosystem studies and forecasting**—Gain sufficient knowledge of Alaskan ecosystems to forecast their response to both natural and anthropogenic change.
2. **Climate change and variability**—Foster climate research targeted at societal needs and advance Arctic climate research to improve predictive capacity of climate variations affecting coastal regions and ecosystems.

Likewise, the results of the RUSALCA projects assist NOAA in two of its Mission Goals: (1) *Healthy oceans:* Protect, restore, and manage the use of coastal and ocean resources through an ecosystem approach to management; (2) *Climate adaptation & mitigation*: Understand climate variability and change to enhance society's ability to plan and respond.

Throughout the RUSALCA award, 17 funding amendments (Appendix 1) were received by CIFAR principal investigators (PIs) totaling $1.6M. Although this five-year award has ended, the RUSALCA research is still developing because much of the Arctic was unknown in 2008 and the sampling strategies necessary to address spatial and temporal variability in physical, chemical, and biological measurements would require refinements that were apparent only after repeated measurements had been made.

As suggested in July 2011 by the NOAA Science Advisory Board appointed panel that provided an external review of the research, education, and outreach programs of CIFAR, efforts are underway to synthesize RUSALCA results for the generation of specific hypotheses or models that can enhance the data already collected and data to be collected in the future. UAF researchers from all five CIFAR RUSALCA projects participated in the RUSALCA Decadal Review Meeting held May 21–23, 2013 in St. Petersburg, Russia. This international gathering presented findings of the first decade of RUSALCA field studies and allowed identification of key synthesis tasks, their potential participants, and task leaders. The presentations made at this synthesis meeting can be found here: http://www.arctic.noaa.gov/aro/russian-american/2013_synthesis/

Four of the CIFAR principal investigators received funding that began 1 July 2013 as amendments to NA13OAR4320056, the CIFAR renewal agreement, to continue the RUSALCA research funded through the 5-year CIFAR RUSALCA shadow award (NA08OAR4320870) and begin synthesis efforts. In addition, Hopcroft has received funding for continuing RUSALCA data management efforts with a team at the Alaska Ocean Observing System (AOOS) that was begun under CIFAR's institutional cooperative agreement (NA08OAR4320751).

Because the Alaska portion of RUSALCA was funded through the experimental "shadow award process" that has been discontinued, CIFAR was not granted the automatic one-year no-cost extension (NCE) when these awards expired on 31 March 2013. Instead a 3-month NCE was granted to allow NOAA Grants Management Division to establish the renewal CIFAR institutional cooperative agreement with the understanding that de-obligated funds on the shadow awards could be transferred to the CIFAR renewal agreement. This process, begun before the RUSALCA award expired, is still in progress.

Highlights of the RUSALCA program

- The Bering Strait mean annual water mass transport was found to have increased by ~50% from 2001 (~0.7Sv) to 2011 (~1.1 Sv), driving heat and freshwater influxes into the arctic.
- A pan-Arctic assessment of nutrient fluxes made from estimates from Bering Strait, Davis Strait, Fram Strait and the Barents Sea, co-authored by RUSALCA PI Terry Whitledge and including RUSALCA data, found that the most important imports of nitrate and phosphate were from the Barents Sea opening while the most important import of silicate was from Bering Strait. The Arctic Ocean was found to be a net exporter of silicate and phosphate to the North Atlantic.
- Biological samples collected on the 2012 cruises are still being processed so results on the major temporal effects upon zooplankton, benthic invertebrates, and fish will be forthcoming.

RUSALCA's role in education

As shown in Appendix 2, sixteen UAF students received support from CIFAR RUSALCA projects. Of these students, three Ph.D. students and one M.S. student have received one or more years of CIFAR support at more than 50% full-time equivalent. Elizaveta Ershova, a marine biology student has been integral to the RUSALCA zooplankton studies, Jonathan Whitefield, a physical oceanography student to the physical oceanography field and modeling investigations, and Michael Kong, a chemical oceanography student to field and laboratory studies of nutrient and primary productivity processes. Elizaveta and Jonathan are still pursuing their Ph.D. degrees; Michael has left UAF without completing his degree. Carlos Serratos is continuing work on his M.S.

Publications and presentations

Forty-two conference presentations (both national and international) were made 1 July 2008–30 June 2013. Three peer-reviewed and one non-peer-reviewer papers were published, with one additional paper in press and several others under preparation.

Additionally, 20 papers were published during this period that stemmed in whole or in part from funding for these projects under the previous CIFAR institutional cooperative agreement, NA17RJ1224.

Final reports for each CIFAR-funded RUSALCA project follow this overview.

RUSALCA: A long-term census of Arctic zooplankton communities

Russell R. Hopcroft, PI ***CIFAR theme: Ecosystem Studies & Forecasting***
University of Alaska Fairbanks

Other investigators/professionals associated with this project:
Ksenia Kosobokova, *Russian partner****,*** *Russian Academy of Sciences, Moscow*

NOAA Goals: Healthy Oceans; Climate Adaptation & Mitigation

NA08OAR4320870 Amendments 1, 8 & 14 NOAA Office: OAR-CPO, Ko Barrett, Sponsor

Primary objectives

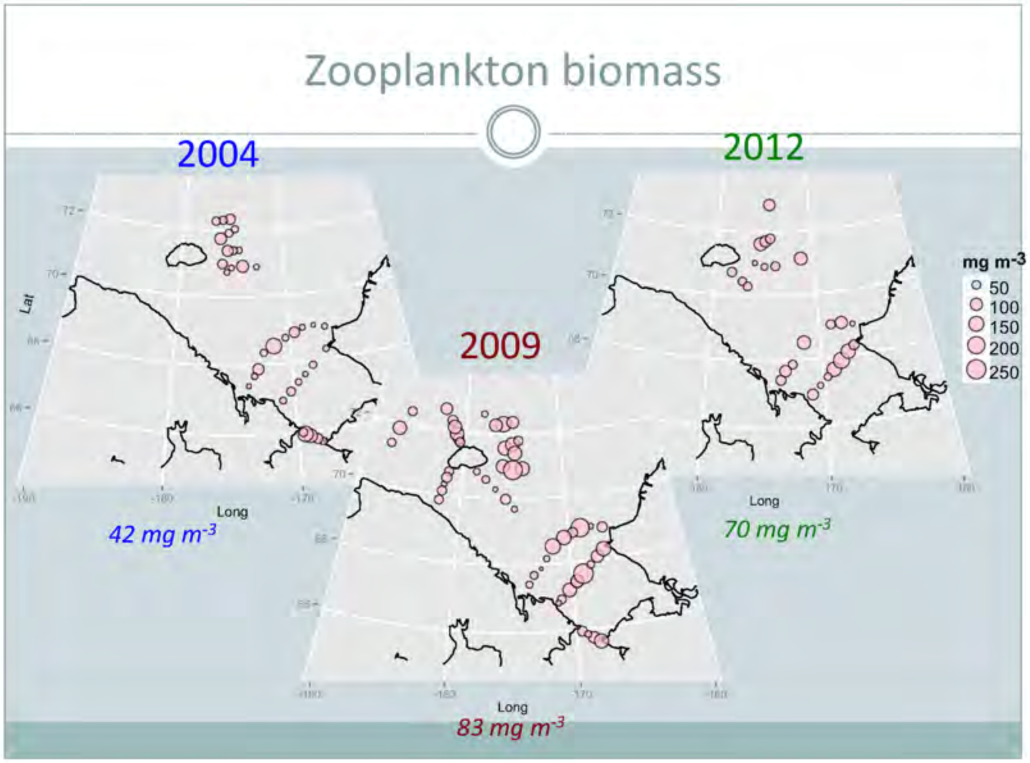
We propose repeated comprehensive surveys of zooplankton communities in the Bering Strait and Chukchi Sea to understand the transport patterns of Pacific zooplankton into the Arctic and build a time-series to assess ecosystem change in this climatically sensitive region. The census will involve a combination of traditional taxonomic enumeration and identification, along with continued molecular sequencing and photographic documentation of the species collected by several types of plankton nets. This work will build on similar efforts from RUSALCA-2004, recent work in the Canada Basin under the Ocean Exploration program, and will temporally extend transects occupied by the Shelf-Basin-Interactions program, and tie into efforts by the International Polar Year and Census of Marine Life for a pan-Arctic program.

Research accomplishments/highlights/findings

Major cruises were completed in 2009 (63 stations) and 2012 (31 stations), with minor expeditions in 2010 (15 stations) and 2011 (12 stations) that encompassed only the southern stations. To assess the 'health' of the zooplankton populations in the region, egg production experiments were conducted at 32 stations in 2009 and 18 stations in 2012, primarily with *Pseudocalanus*, the dominant copepod genus in this region. Photographic documentation of the fauna of the region started in 2004 was continued in 2009 and 2012, along with samples taken for molecular characterization.

As observed in 2004, the differences in zooplankton communities encountered on subsequent cruises have been striking. In 2009, strong across-shelf differences occurred in the northern sampling domain, and strong east-west gradients occurred in the southern Chukchi Sea. The copepod *Pseudocalanus* dominated all collections with the exception of the northernmost stations on the Chukchi Plateau, followed by variable numbers of *Calanus* copepods and the chaetognath *Parasagitta elegans*. Small jellyfish were common or even abundant at the northwestern stations, while large jellyfish became common only in the southern Chukchi. Ctenophores, particularly *Mertensia* and *Bolinopsis* were present at most stations, and their abundance quantified. Alaska Coastal Current water had abundant populations of the pteropod *Limacina helicina*. Compared to 2004, meroplankton and the larvacean *Oikopleura vanhoeffeni* were less abundant, although it is unclear if this reflects a between-year variation or differences in seasonal timing of the cruise. Like 2004, many of the stations had extremely thick communities of phytoplankton retained by our nets. Species composition of *Pseudocalanus* was variable across the sampling region, as were their rates of reproduction. Cluster analysis and Multidimensional Scaling using the Bray-Curtis community similarity reveals distinct clustering of the stations. Notably, the Alaska Coastal Current is not as distinctly identified in 2009, but once again results suggest water from the Bering Sea can be traced as far as Herald Valley using the zooplankton fauna.

During 2010, 2011 and 2012, stronger east-west patterns were apparent with Alaska Coastal Water, Bering Water and Siberian Coast Water (as observed in 2004). Zooplankton abundance and biomass values are more similar to 2009 than those observed in 2004. During 2012, egg production experiments were performed at several of these stations to more directly explore the influence of temperature on egg production – it confirms reproductive performance of the Pacific and Arctic species is optimized at different temperatures and this likely explains the maintenance of their observed distributions. Efforts are ongoing to combine the RUSALCA data sets with other zooplankton observations from the Chukchi Sea.



NOAA relevance/societal benefits

This project examines the potential impacts of climate change in the Pacific–Arctic gateway.

Education

A dual citizen student, Elizaveta Ershova, began her Ph.D. jointly supervised by Hopcroft and Kosobokova, and splits her time between UAF and Shirshov Institute, Moscow.

In addition, the cruises provided valuable experience to two graduate student volunteers who assisted with this project—Cornelia Jaspers (Danish Technical University) in 2009 and Imme Rutzen (UAF School of Fisheries and Ocean Sciences) in 2012.

Outreach

Hopcroft, through ArcOD (Arctic Ocean Biodiversity Project), continues to develop webpages providing information on Arctic zooplankton and access to historical datasets: see http://www.arcodiv.org/. The species page concept has been expanded upon through a related fellowship by the Encyclopedia of Life to Ershova, that will be merged with ArcOD content over time.

Publications and conference presentations

Peer-reviewed publication

Hunt, G.L. Jr., A.L. Blanchard, P. Boveng, P. Dalpadado, K.F. Drinkwater, L. Eisner, R.R. Hopcroft, K.M. Kovacs, B.L. Norcross, P. Renaud, M. Reigstad, M. Renner, H.R. Skjoldal, A. Whitehouse and R.A. Woodgate. 2013. The Barents and Chukchi Seas: Comparison of two Arctic shelf ecosystems. Journal of Marine Systems 109–110:43–68. doi:10.1016/j.marsys.2012.08.003

In-press peer-reviewed publication

Nelson, R.J., R.R. Hopcroft, K.N. Kosobokova, B.P.V. Hunt and K. Young. Biodiversity and biogeography of metazoan zooplankton of the Pacific Arctic Region – Sensitivities to climate change. In: J.M. Grebmeier, W. Maslowski and J. Zhao, Eds. The Pacific Arctic Sector: Status and Trends. Springer, New York, in press.

Papers under preparation

Two manuscripts are currently under preparation—one on comparison of communities between years, and one on egg production.

Oral presentations

Hopcroft, R.R., K.N. Kosobokova, and 20 others. 2010. A pan-Arctic analysis of biodiversity patterns for zooplankton on Arctic shelves. Invited presentation, Arctic Frontiers Meeting, Tromso, Norway, January 2010.

Ershova, E.A., R.R. Hopcroft and K.N. Kosobokova. 2012. A multi-year census of the zooplankton communities in the Pacific Arctic. Wakefield Symposium, March 2013, Anchorage, Alaska.

Poster Presentations

Rutzen, I., F. Huettmann and R.R. Hopcroft. 2010. Predicting zooplankton abundance and distribution throughout the Arctic Ocean. Poster, Arctic Frontiers Meeting, Tromso, Norway, January 2010.

Rutzen, I., F. Huettmann and R.R. Hopcroft. 2010. Predicting zooplankton abundance and distribution throughout the Arctic Ocean. Poster, Alaska Marine Science Symposium, Anchorage, Alaska, January 2010.

Hopcroft, R.R,. K.N. Kosobokova and E.A. Ershova. 2010. RUSALCA: Census of the arctic zooplankton. RUSALCA PI meeting. 9–12 October 2010, Kotor, Montenegro.

Ershova, E.A, R.R. Hopcroft and K.N. Kosobokova. 2011. Broadscale patterns of summer zooplankton communities in the Chukchi Sea during 2004 and 2009. 5th International Zooplankton Production Symposium, March 2011, Pucon, Chile.

Ershova, E.A., R.R. Hopcroft and K.N. Kosobokova. 2012. A multi-year census of the zooplankton communities in the Pacific Arctic. Alaska Marine Science Symposium, January 2012, Anchorage, Alaska.

Ershova, E.A., R.R. Hopcroft and K.N. Kosobokova. 2012. A multi-year census of the zooplankton communities in the Pacific Arctic. ASLO/AGU Ocean Sciences Meeting, February 2012, Salt Lake City, Utah.

Ershova, E.A., R.R. Hopcroft and K.N. Kosobokova. 2012. A multi-year census of the zooplankton communities in the Pacific Arctic. RUSALCA PI meeting, March 2012, Miami, Florida.

Ershova, E.A., R.R. Hopcroft and K.N. Kosobokova. 2013. Inter-annual variation in the spatial patterns of *Pseudocalanus* species distribution and egg production. Alaska Marine Science Symposium, January 2013, Anchorage, Alaska.

Ershova, E.A., R.R. Hopcroft and K.N. Kosobokova. 2013. Spatial patterns of *Pseudocalanus* species distribution and egg production in the Pacific Arctic. ASLO Meeting, February 2013, New Orleans, Louisiana.

Peer-reviewed publications published during this funding period but arising from support to this project under the previous cooperative agreement NA17RJ1224

Bucklin, A., R.R. Hopcroft, K.N. Kosobokova, L.M. Nigro, B.D. Ortman, R.M. Jennings and C.J. Sweetman. 2010. DNA barcoding of Arctic Ocean holozooplankton for species identification and recognition. *Deep Sea Research II*, 57:40–48. doi: 10.1016/j.dsr2.2009.08.005

Hopcroft, R.R. and K.N. Kosobokova. 2010. Distribution and egg production of Pseudocalanus species in the Chukchi Sea. *Deep Sea Research II*, 57:49–56. doi: 10.1016/j.dsr2.2009.08.004

Hopcroft, R.R., K.N. Kosobokova and A.I. Pinchuk. 2010. Zooplankton community patterns in the Chukchi Sea during summer 2004. *Deep Sea Research II*, 57:27–39. doi: 10.1016/j.dsr2.2009.08.003

Other products and outcomes

Hopcroft is working in conjunction with NOAA toward the development of a Circumpolar Biodiversity Monitoring Program (CBMP) under the International Arctic Council within which the RUSALCA program will represent a significant component from the USA. Hopcroft also provides oversight on the RUSALCA data management project.

Partner organizations and collaborators

Arctic Ocean Biodiversity Project (ArcOD)

RUSALCA: Arctic food web structure and epibenthic communities in a climate change context

Katrin Iken, PI
Bodil A. Bluhm, PI
University of Alaska Fairbanks

CIFAR theme: Ecosystem Studies & Forecasting

Other investigators/professionals associated this project:
Ken Dunton, *University of Texas at Austin*
NOAA Goals: Healthy Oceans; Climate Adaptation & Mitigation

NA08OAR4320870 Amendments 2, 9, 13 &15 NOAA Office: OAR-CPO, John Calder/Kathleen Crane, Sponsor

Primary objectives

The primary objectives are to contribute to RUSALCA goals by linking physical and chemical observations of water mass characteristics to food web structure and epibenthic faunal assemblages. First, we propose that food web analysis is a meaningful quantitative key variable for long-term climate observations. Benthic ecosystems act as indicators of long-term of change in marine systems because they tend to integrate both seasonal and inter-annual variability in overlying water column processes. Secondly, we propose to analyze epibenthic community structure as an indicator for ocean current regime and sediment patterns. In collaboration with working groups investigating infauna, we propose to monitor epifaunal community trends in the RUSALCA region.

Research accomplishments/highlights/findings

We participated in two interdisciplinary research cruises during the course of this project, one in 2009 and one in 2012 (plus one completed in 2004 under a previous RUSALCA project). Samples for epifaunal community structure and samples from water column production, zooplankton, infauna, epifauna, and fish for food web analysis were collected during these cruises. All samples from the 2009 cruise have been analyzed for both epifaunal community and stable isotope analyses for food web structure. Samples for 2012 are being processed by Carlos Serratos, an M.S. student working on this project. All isotope samples have been processed and now await measurement at the Alaska Stable Isotope Facility.

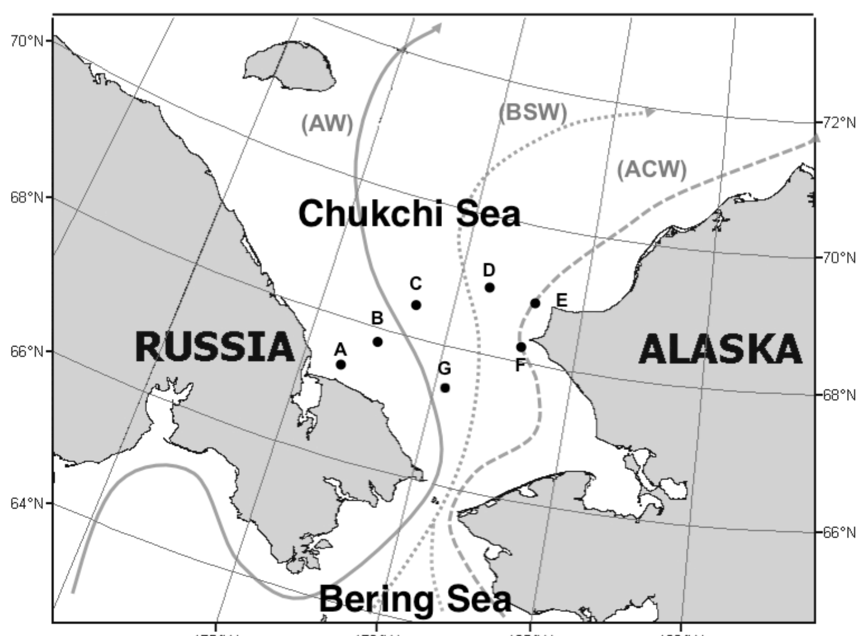


Figure 1. Map of the southern Chukchi Sea study region showing station locations A-F sampled in all three study years (2004, 2009, 2012) for interannual comparisons.

Serratos has now collated and standardized all data matrices from the three cruises to a common identification level, and updated any taxonomic name changes for a temporal (2004–2012) comparison of epibenthic community structure at seven stations sampled in all three sampling years (Figure 1). At the level for which taxonomic identifications are currently confirmed for the three years, 94 taxa match among the three years. Mean epibenthic abundance increased from 2004 (8,491 individuals (ind) 1000 m^{-2}) to 2012 (11,533 ind. 1000 m^{-2}) across the seven compared stations in the southern Chukchi Sea. Not all individual stations, however, reflected a linear increase in abundance over this time and exhibited much variability in patterns of abundance and relative contribution of phyla to total abundance (Figure 2). Particularly the large abundance increase at station B in 2009 and at station G in 2012 (Figure 2) contributed much to the overall pattern. Much of this overall abundance increase can be attributed to arthropods. Mean epibenthic biomass increased from 2004 (27,162 g wet weight 1000 m^{-2}) to 2009 (59,890 g wet weight 1000 m^{-2}) and declined in 2012 (18,442 g wet weight 1000 m^{-2}), yet again with much variability across the seven stations (Figure 3). The overall pattern in total biomass is mainly driven by a strong increase in total biomass at stations B, C and G between 2004 and 2009, followed by a sharp decline in 2012, a trend that was again mainly driven by arthropods. Despite differences in absolute abundance and biomass in epibenthic communities among years, water mass seemed to maintain certain characteristics in community structure. For example, Anadyr Water had higher mollusk abundance than Alaska Coastal Water while the latter had higher arthropod abundances (Figure 4). The similarity between stations in nonmetric multi-dimensional scaling was primarily driven by sampling location rather than by year (Figure 5). The most dissimilar site from all other locations among years was site F, a location with hard substrate that influences the taxon composition compared to soft bottom locations. As soon as the environmental variables measured in 2012 become available, an environmental matrix will be compiled for all years and be used to identify the most important drivers of epifaunal community structure. Our preliminary conclusion is that the bulk variables abundance and biomass varied between years with no clear trend, but that community structure remained relatively similar between years.

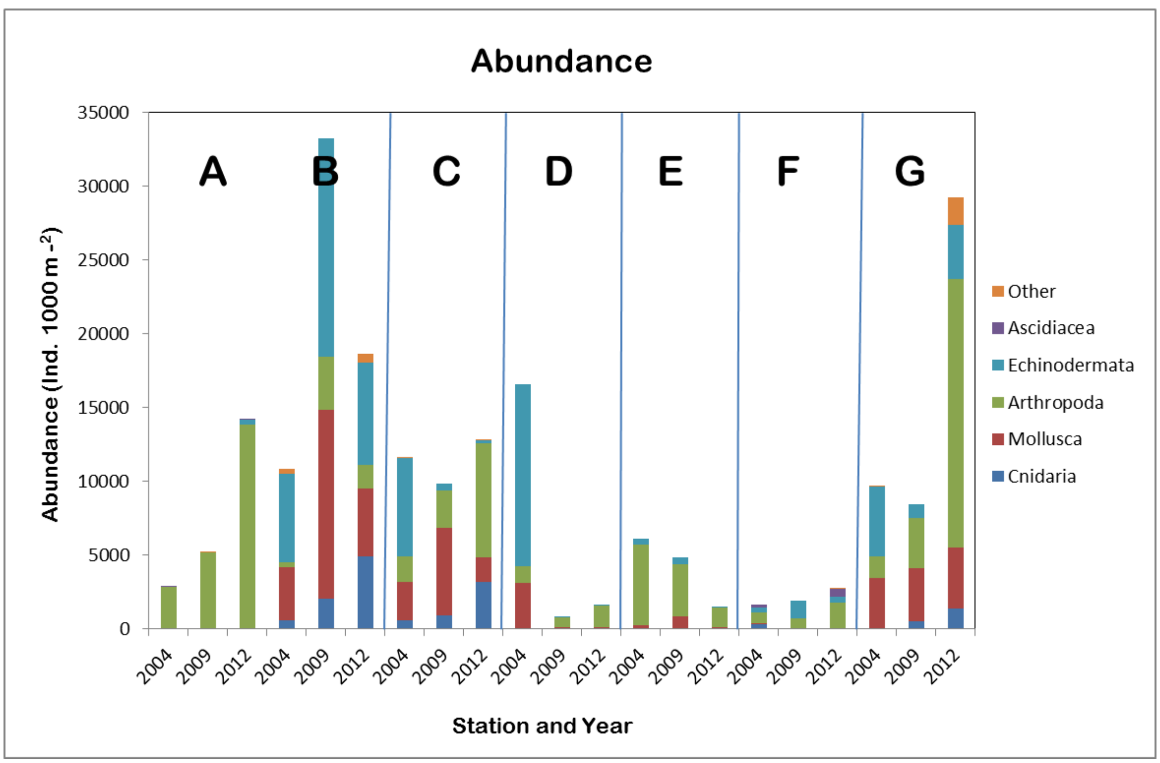


Figure 2. Epibenthos abundance (number of individuals 1000 m^{-2}) with absolute contributions of major taxa at seven repeat sampling stations over the three study years (2004, 2009, 2012). Station names as in Figure 1.

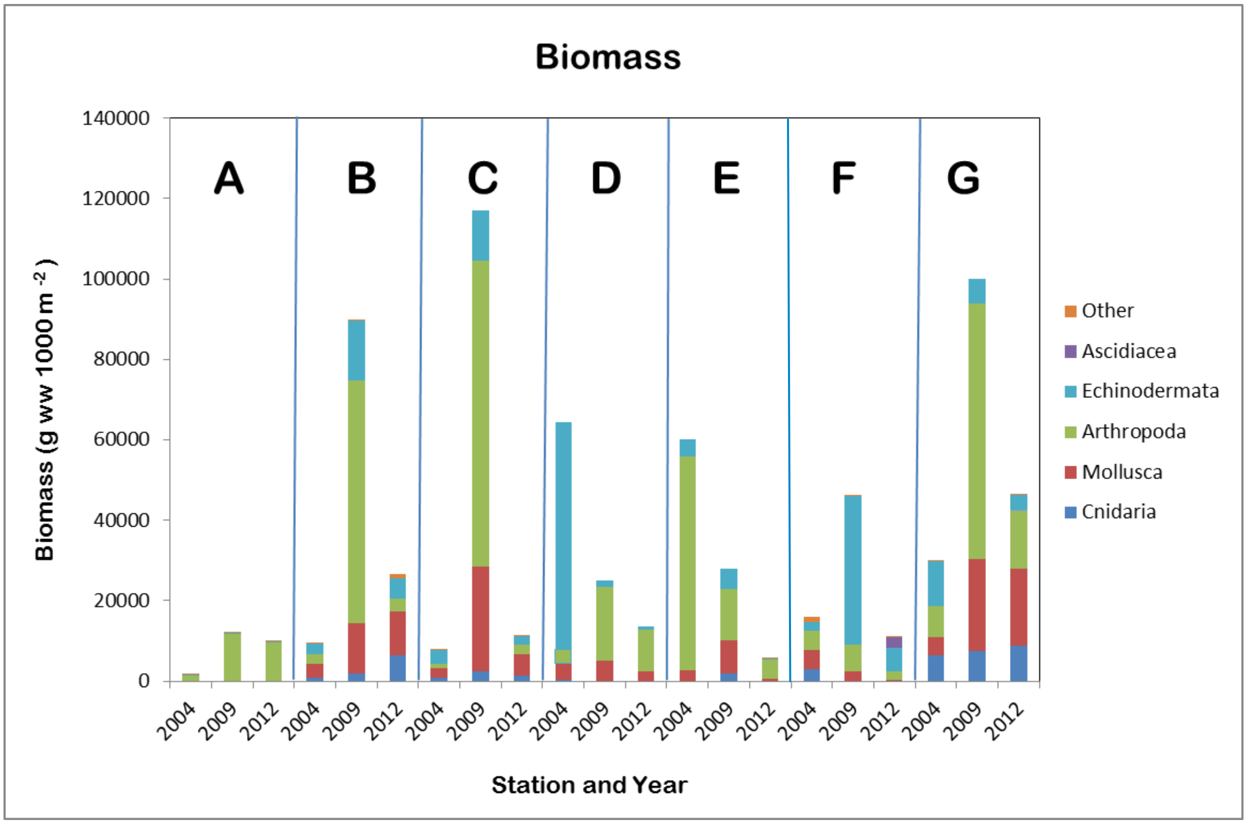


Figure 3. Epibenthos wet biomass (gram wet weight 1000 m^{-2}) with absolute contributions of major taxa at seven repeat sampling stations over the three study years (2004, 2009, 2012). Station names as in Figure 1.

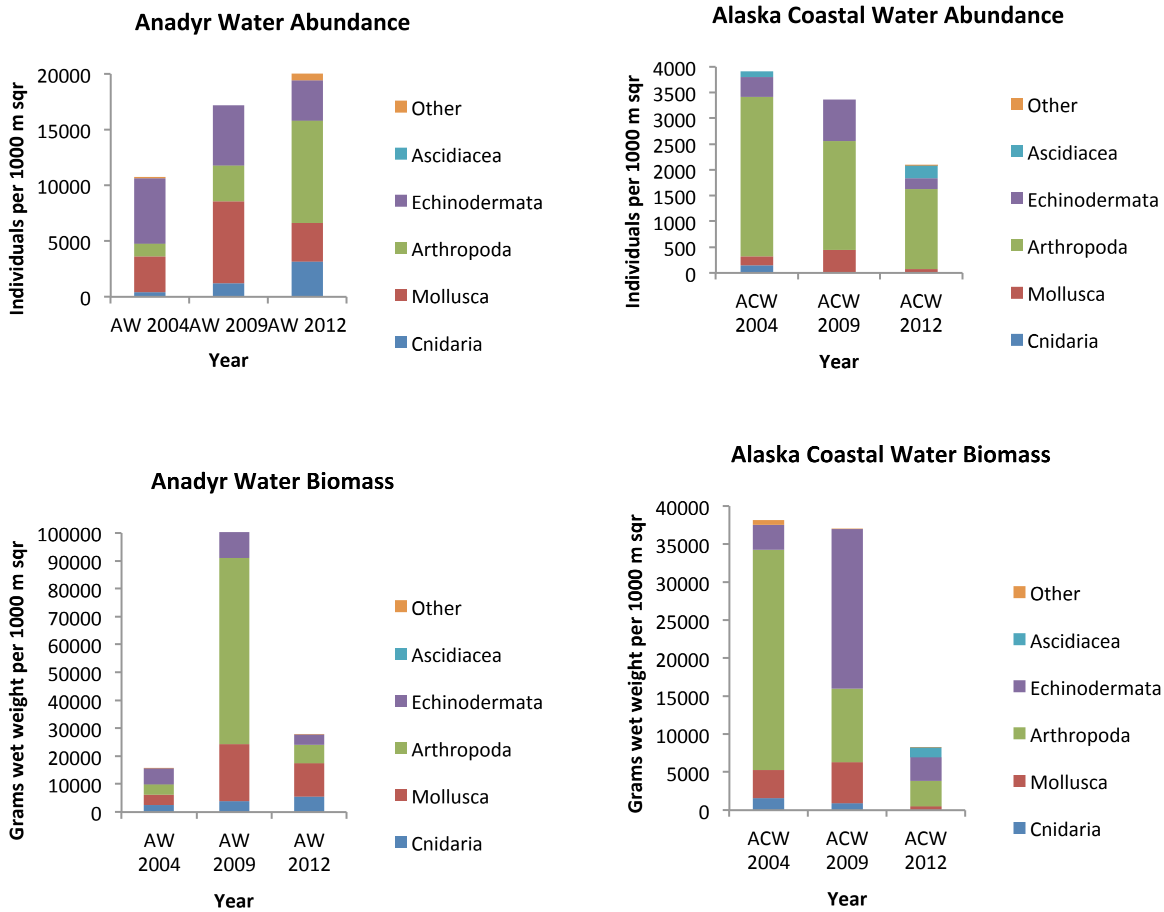


Figure 4. Mean epibenthos abundance (number of individuals 1000 m^{-2}) and wet biomass (gram wet weight 1000 m^{-2}) among years at the two main water masses in the region, the Anadyr Water to the west and the Alaska Coastal Water to the east.

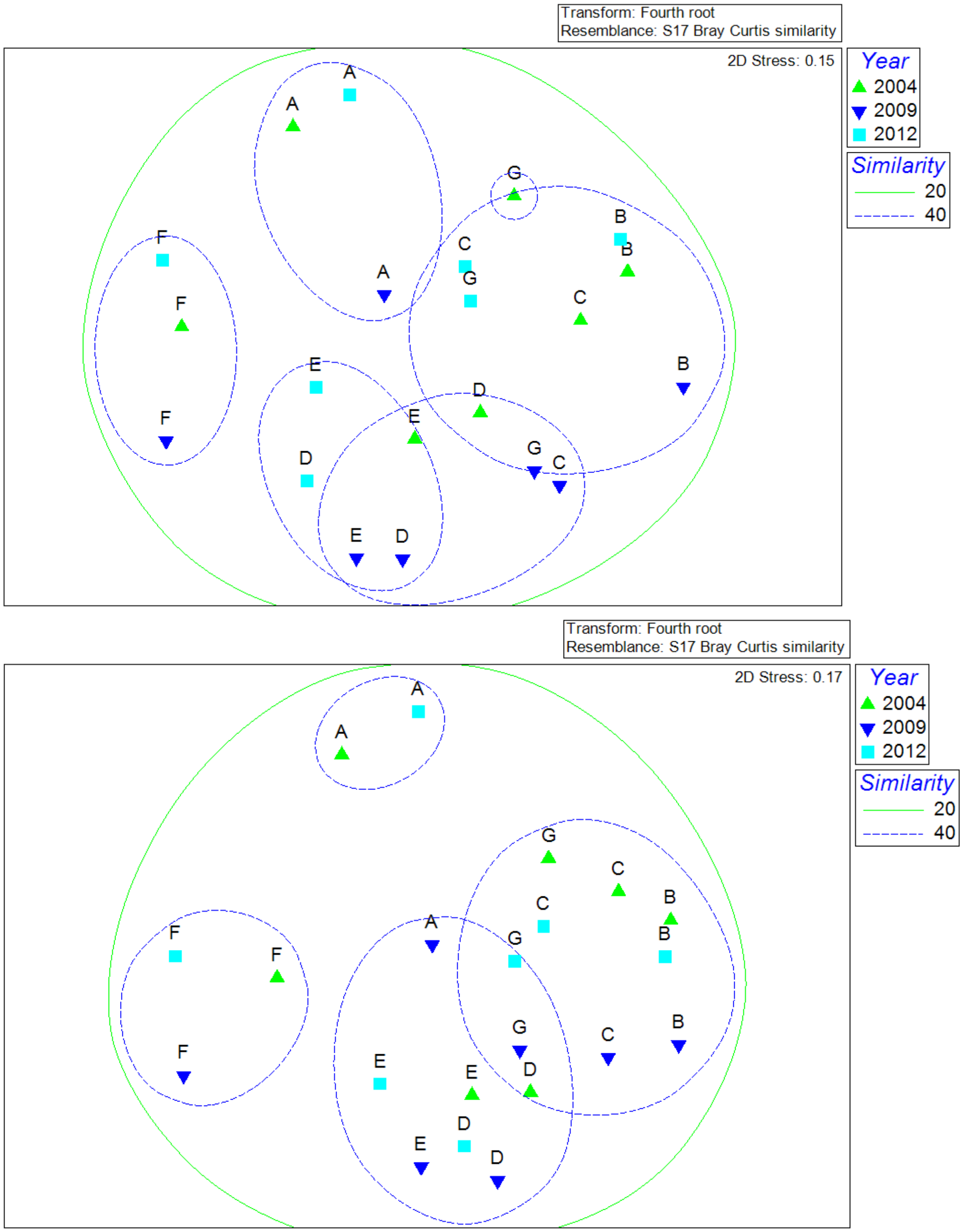


Figure 5. Non-metric multi-dimensional scaling plots of epibenthic community structure at seven stations in the southern Chukchi Sea between 2004-2012

We established in a comparison of stable isotope data from 2004 and 2009 that overall food web structure in relation to water mass characteristics is relatively stable among years, making this community metric a good indicator of long-term change. Variability was mostly detected in the particulate organic matter (POM), the primary food source for the system. This variability is likely derived from the variable influence of freshwater among years (e.g., strength of Alaska Coastal Current and/or Siberian Coastal Current), or by the interannually variable influence of ice algae (typically enriched in $\delta^{13}C$ isotope ratios). We will explore these patterns further once we receive the 2012 data from the Stable Isotope Facility.

During the 2009 and 2012 cruises, we took the opportunity to analyze population structure parameters of snow crab (*Chionoecetes opilio*). These data contribute to our Bureau of Ocean Energy Management (BOEM), Coastal

Marine Institute (CMI)-funded project on the population structure and reproductive ecology of Arctic snow crab. Snow crabs were measured for individual wet weight, carapace width, shell condition, and chela height. Spermathecae were dissected from mature females and clutch fullness and ovary color were determined and eggs counted for fecundity estimates. These data will contribute to our growing database on snow crab from the Chukchi and Beaufort shelves, which shows that snow crab are numerous on the Chukchi shelf but are small in body size, while they are more sparse but large in size (considered commercial size based on Bering Sea standards) on the deeper Beaufort Sea slope (deeper than about 200 m depth). Fecundity is primarily related to body size as it is farther south.

NOAA relevance/societal benefits

This work contributes to NOAA's strategic plan objective "to describe and understand the state of the climate system through integrated observations" of the biological components and the associated water mass characteristics. Increased knowledge of food web connections and epibenthic communities will be essential information to "understand the consequences of climate variability and changes" in the Chukchi Sea marine ecosystem. This work provides NOAA with a product that can assist to "improve society's ability to plan and respond to climate variability." Knowledge gained during the RUSALCA work has contributed to the development of the Circumpolar Biodiversity Monitoring Program (CBMP) Implementation Plan (Arctic Council).

Education

Two University of Alaska Fairbanks-based graduate students participated in the cruises and gained valuable field experience during these cruises: Jared Weems participated in the 2009 cruise and Lauren Bell participated in the 2012 cruise. In addition to field experience, the cruises provided these students with the opportunity to work with an international and interdisciplinary team of renowned scientists. A third graduate student, Carlos Serratos, started in Fall 2012 on the project for his M.S. thesis and is looking at the temporal comparison (2004–2012) of the epibenthic community and food web structure in the southern Chukchi Sea. He worked on data management of epifaunal community data for the three sampling years to match taxa in the database, identify taxa that needed to be voucher identified, and prepare epifaunal data for analysis with the software program Primer. Carlos also has processed all the stable isotope samples for the 2012 (and some additional 2009) collections. He presented his preliminary results on epifaunal community structure in a poster at the Alaska Marine Science Symposium in January 2013 (see below). He also has received funding from the Center for Global Change Student Research Competition for some bridge funding for summer salary.

An undergraduate student (Colton Lipka, Fisheries major) processed snow crab collected during the 2009 RUSALCA cruise to contribute to the above mentioned project on Arctic snow crab population structure funded by the Coastal Marine Institute (CMI). His lab work satisfies the "Experiential learning" class requirement through the UAF undergraduate Fisheries degree. Several other undergraduate students and a volunteer received lab training on crab measurements as well. UAF undergraduate minority student Dominic Hondolero, under the supervision of Iken and Bluhm, was awarded CIFAR International Polar Year (IPY) funding to determine energy content of dominant Chukchi Sea benthic fauna, for which he used RUSALCA samples.

Outreach

During the cruises, we contributed to the 2009 NOAA Ocean Exploration cruise website (http://oceanexplorer.noaa.gov/explorations/09arctic/logs/sept24/sept24.html), to 2009 and 2012 web blogs of a participating PolarTREC teacher on board (http://arctic.cbl.umces.edu/RUSALCA/), and the 2012 NOAA Ocean Exploration cruise website (http://oceanexplorer.noaa.gov/explorations/12arctic/background/biodiversity/biodiversity.html and http://oceanexplorer.noaa.gov/explorations/12arctic/logs/sept2/sept2.html). We also provided pictures to illustrate this website as well as NOAA's RUSALCA web site http://www.arctic.noaa.gov/aro/russian-american/2012/photos4.html. We also contributed to the teacher-at-sea's blog on the Polar Trec web site: http://www.polartrec.com/expeditions/russian-american-long-term-census-of-the-arctic. We shared pictures taken during the RUSALCA cruises with media and other interested parties.

Publications and conference presentations

Publications in planning

Serratos, C.R., B.A. Bluhm and K. Iken. Temporal trends in epibenthic community and food web structure in the southern Chukchi Sea. [*Peer-reviewed publication as part of C. Serratos' M.S. thesis*].

Oral presentations

Bluhm, B.A., K. Iken, B.I. Sirenko, S.M. Hardy, B.A. Holladay and K. Dunton. 2012. Food web structure and epibenthic megafauna in the Chukchi Sea: A comparison between 2004 and 2009. Ocean Sciences Conference, 20–24 February 2012, Salt Lake City, Utah.

Iken, K., B. Bluhm, B. Sirenko, S. Hardy, B. Holladay and K. Dunton. 2012. Temporal trends in epibenthic megafauna and food web structure in the Chukchi Sea. RUSALCA Planning Meeting, 10–12 March 2012, Miami, Florida.

Bluhm, B. and K. Iken. 2013. Population assessment of snow crab, *Chionoecetes opilio*, in the Chukchi and Beaufort Seas: Preliminary findings. 28th Lowell Wakefield Symposium, 26–29 March 2013, Anchorage AK. [*This presentation included data on snow crab collected during the 2004-2012 RUSALCA cruises*]

Bluhm, B.A., B.L. Norcross, K. Iken, F. Huettmann and B. Holladay. 2013. Fish and epibenthic assemblages in the Chukchi Sea: observations and predictions. RUSALCA PI meeting, St. Petersburg, Russia, May 2013.

Bluhm, B.A., K. Iken, C. Serratos and B. Sirenko. 2013. Temporal comparison of epifauna and food web in the southern Chukchi Sea (2004, 2009, 2012): First results. RUSALCA PI meeting, St. Petersburg, Russia, May 2013.

Poster presentations

Iken, K., B. Bluhm, B.I. Sirenko, S.M. Hardy, B.A. Holladay, J. Weems and K. Dunton. 2011. Food web structure and epibenthic megafauna in the Chukchi Sea—a temporal comparison. Alaska Marine Science Symposium, 17–20 January, Anchorage, Alaska.

Serratos, C., B. Bluhm and K. Iken. 2013. A preliminary temporal comparison of epibenthic community structure in the southern Chukchi Sea from 2004–2012. Alaska Marine Science Symposium, 21–25 January 2013, Anchorage AK.

Bluhm, B. and K. Iken. 2013. Population assessment of snow crab, *Chionoecetes opilio*, in the Chukchi Sea. Alaska Marine Science Symposium, 21–25 January 2013, Anchorage AK.

Divine, L., K. Iken and B. Bluhm. 2013. Can you stomach it?: preliminary diet and stable isotope analysis of snow crab (*Chionoecetes opilio*) in the Alaskan Arctic. 28th Lowell Wakefield Symposium, 26–29 March 2013, Anchorage AK. [*This presentation included data on snow crab collected during the 2012 RUSALCA cruise*]

Peer-reviewed publications published during this funding period but arising from support to this project under the previous cooperative agreement NA17RJ1224

Bluhm, B.A., K. Iken, S. Mincks Hardy, B.I. Sirenko and B.A. Holladay. 2009. Community structure of epibenthic megafauna in the Chukchi Sea. *Aquatic Biology,* 7: 269–293. doi:10.3354/ab00198 *(This manuscript is a community composition description from the 2004 RUSALCA cruise)*

Iken, K., B. Bluhm and K. Dunton. 2010. Benthic food-web structure under differing water mass properties in the southern Chukchi Sea. *Deep-Sea Research II*, 57:71–85. *(This manuscript is a food web analysis from the 2004 RUSALCA cruise)*

Sirenko, B.I., B.A. Bluhm, K. Iken, K. Crane and V. Gladish. 2009. Some results of investigation of composition and quantitative distribution of epifauna in the Chukchi Sea. *Exploration of the Faunas of the Seas*, 64(72):200–212. *(This is a manuscript on epibenthic community structure derived from underwater video imaging)*

Piepenburg, D., P. Archambault, W.G. Ambrose Jr., A.L. Blanchard, B.A. Bluhm, M.L. Carroll, K.E. Conlan, M. Cusson, H.M. Feder, J.M. Grebmeier*,* S.C. Jewett, M. Levesque, V.V. Petryashev, M.K. Sejr, B.I. Sirenko and M. Wlodarska-Kowalczuk. 2010. Towards a pan-Arctic inventory of the species diversity of the macro- and megabenthic fauna of the Arctic shelf seas. *Marine Biodiversity,* doi 10.1007/s12526-010-0059-7. (*We contributed biomass, abundance and species diversity data from the Chukchi Shelf from the 2004 RUSALCA cruise to this pan-Arctic synthesis effort.*)

Wei, C.L., G. Rowe, E. Escobar-Briones, A. Boetius, T. Soltwedel, M.J. Caley, Y. Soliman, F. Huettmann, F. Qu, Z. Yu, C.R. Pitcher, R.L. Haedrich, M.K. Wicksten, M.A. Rex, J.G. Baguley, J. Sharma, R. Danovaro, I.R. MacDonald, C.C. Nunnally, J.W. Deming, P. Montagna, M. Lévesque, J.M. Weslawski, M. Wlodarska-Kowalczuk, B. Ingole, B.J. Bett, A. Yool, B.A. Bluhm, K. Iken and B.E. Narayanaswamy. 2010. Global patterns and predictions of seafloor biomass using random forests. *Public Library of Science One,* 5(12): e15323. (*We contributed biomass data from the Chukchi Shelf from the 2004 RUSALCA cruise to this global effort to estimate biomass patterns and to develop predictive models for the global ocean.)*

Hondolero, D., B.A. Bluhm and K. Iken. 2012. Caloric content of dominant benthic species from the Northern Bering and Chukchi Seas: historical comparisons and the effects of preservation. *Polar Biology*, 35:637–644. doi:10.1007/s00300-011-1107-x (*This manuscript contains samples from the RUSALCA project that were measured for caloric content. The first author was an undergraduate student performing the work under a NOAA-CIFAR IPY Student Traineeship grant for undergraduate students (CIPY-03)).*

Partner organizations and collaborators

Bluhm and Iken both were involved with the Census of Marine Life Program, specifically the Arctic Ocean Diversity (ArcOD) project that produced biodiversity-related publications in the past few years. Iken and Bluhm are also co-PIs of a recent National Science Foundation (NSF)-sponsored Bering Sea Ecosystem Studies (BEST) project, which investigates pelagic-benthic coupling in the Bering Sea in relation to sea ice cover. Both PIs are involved with snow crab population and reproductive dynamics work in the Chukchi and Beaufort Seas (CMI-funded), which ties together with RUSALCA objectives and sampling. By advising a Ph.D. student (L. Divine) funded through the NSF-Integrative Graduate Education and Research Traineeship (IGERT) program MESAS (Marine Ecosystem Sustainability in the Arctic and Subarctic) and an M.S. student (L. Bell) funded through the BOEM Transboundary project both PIs also are engaged in analyzing the food web structure on the Beaufort Sea shelf, which links intrinsically to the food web studies performed within the RUSALCA project on the Chukchi shelf. Both PIs also are members of the Marine Expert Monitoring Group of the CBMP, one of the programs under the directive of CAFF (Arctic Council Conservation of Arctic Flora and Fauna), where the RUSALCA program features strongly in monitoring the Chukchi Sea region. Bluhm is funded through the Oil Spill Recovery Institute (OSRI) to rescue historic unpublished data from epifaunal trawl hauls in the Beaufort Sea. Both PIs are involved in current Bureau of Ocean Energy Management (BOEM) programs that investigate snow crab in the Chukchi Sea (Arctic EIS) and epifaunal community and benthic food web structure in the eastern Beaufort Sea (US-Canada Transboundary). Under North Pacific Research Board (NPRB) and Norwegian funding, Bluhm is working with Russian collaborators (several of which are involved in RUSALCA) on editing English versions of Russian-authored taxonomic identification keys for Arctic fauna in an effort to both provide better access to identification material and uniform identifications between Russian and western Arctic researchers. Also under NPRB funding, Bluhm has been compiling benthic epifauna data from across the Pacific Arctic including RUSALCA data with the plan to produce a multi-authored region-wide publication. For the same project, Iken has contributed RUSALCA-collected food web data for a Pacific Arctic compilation.

Changes/problems/special reporting requirements

The 2009 cruise was delayed for one year (originally planned for 2008) and this caused a delay in working up the samples from that cruise with respect to the timeline of this project. Also, Bluhm was on maternity-related family medical leave for 4 months in 2009 and on a reduced contract until 2013, which slowed some of our progress. We also decided in 2011 to search for a graduate student to work on this project but were only able to find a suitable student in 2012. We saved funding from the project to be able to pay a student, which is one reason there are still funds remaining. We therefore submitted a proposal for funds to be deobligated from NA08OAR4320870 amendment 15 for transfer to NA13OAR4320056.

RUSALCA: Fish ecology and oceanography

Brenda L. Norcross, PI
University of Alaska Fairbanks

CIFAR theme: Ecosystem Studies & Forecasting

Other investigators/professionals associated with this project:
Brenda A. Holladay, Co-PI, *University of Alaska Fairbanks*
Morgan S. Busby, *Senior Investigator, Alaska Fisheries Science Center (AFSC), Seattle*

NOAA Goals: Healthy Oceans; Climate Adaptation & Mitigation

NA08OAR4320870 Amendments 3, 10, 11, & 17 NOAA Office: OAR-CPO, John Calder/Kathleen Crane, Sponsor

Primary objectives

We hypothesized that climate change, specifically a reduction of sea ice cover in the northern Bering and Chukchi Seas, will alter the species composition, abundance and distribution of fishes. Our objectives were to:

- Collect larval and juvenile fishes in specific water masses to estimate relative fish abundance and distribution.
- Determine ichthyoplankton and juvenile demersal fish assemblages (species composition).
- Determine physical and oceanographic features (water masses) characteristics that define ichthyoplankton and juvenile demersal fish habitat.

Research accomplishments/highlights/findings

During the September 2009 cruise aboard the Professor Khromov, the Fish Ecology Project Team used a 60 cm diameter net with 0.505 mm mesh bongo net to collect ichthyoplankton (planktonic fish eggs and larvae) at 31 stations and a small (7 mm) mesh bottom trawl (3 m plumb staff beam trawl) to collect juvenile and small adult demersal fishes at 22 stations. The ichthyoplankton net captured only 22 fish larvae of 11 species. The beam trawl collected 10,323 fish, with at least 41 species represented. Analysis of combined 2004 and 2009 RUSALCA bottom trawl collections showed that adding more sample sites provides a clearer picture of fish communities. Analysis of 1959–2008 demersal fish collected with several gear types showed that the average length of fishes in the Chukchi Sea is small even when collected with a large mesh net, and that a small mesh net yields greater diversity of fishes ([1]Norcross et al. 2012).

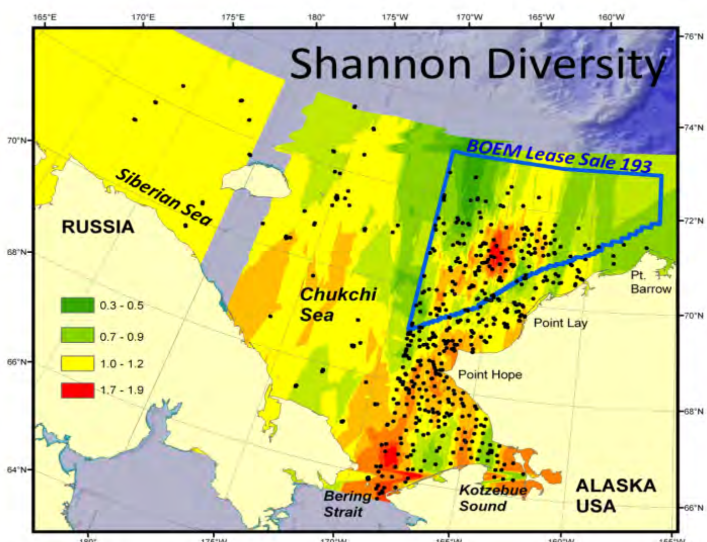


Figure 1. Shannon Diversity Indices incorporate abundance and evenness measures. The higher numbers and brighter colors on this map indicate greater diversity. Results from RUSALCA-2004 and RUSALCA-2009 bottom fish collections were included in an evaluation of all fisheries collections in the Chukchi Sea between 1959 and 2009 (black dots). Including large quantities of data allowed patterns of diversity to be seen.

Results from RUSALCA-2009 collections were included in an evaluation of all demersal fisheries collections in the Chukchi Sea between 1959 and 2009 ([2]Norcross et al. 2012). Diversity of fish communities appears to be highest in eastern Bering Strait and an area in the northeastern Chukchi Sea (Figure 1). Diversity in the northern Chukchi Sea is relatively low, and an intermediate level of diversity exists in the eastern Siberian Sea, eastern and central Chukchi Sea. Collections we made with the 3 m plumb staff beam 2004–2009 show the spatial extent of demersal fish communities in the Chukchi Sea and the taxonomic families that make up four communities (Figure 2). Each station was assigned to a community based on abundances of fish species at that station. Sculpins and pricklebacks were abundant in all four communities, with sculpins being more abundant in the central Chukchi Sea (Community l) and pricklebacks being more abundant in communities c, k, and m. Eelpouts were more abundant in the north (Community c) than further south. Cods (primarily the Arctic cod *Boreogadus saida*) were most abundant in the north and central Chukchi Sea (Communities c and l). Flatfishes were more abundant in the eastern Chukchi Sea (Community m) than elsewhere.

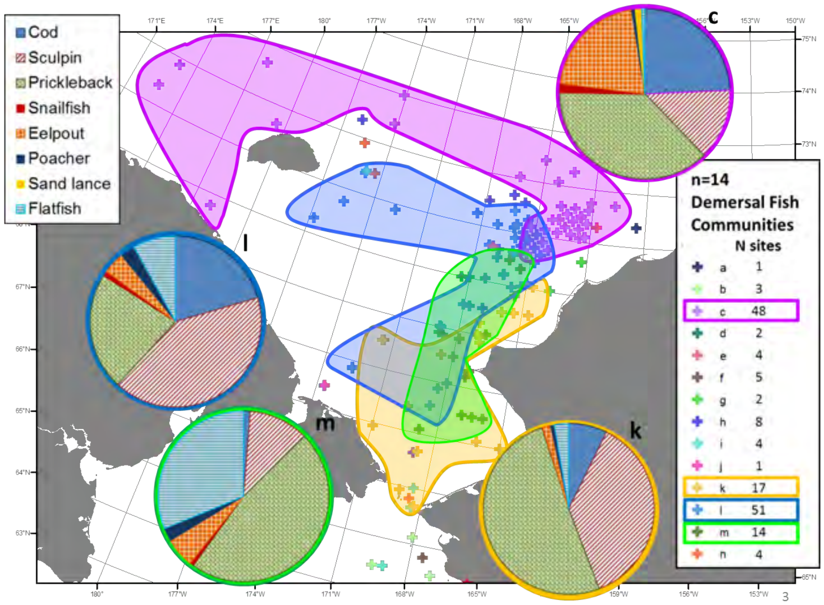


Figure 2. Map of spatial extent of demersal fish communities in the Chukchi Sea, as determined by cluster analysis of fish abundance (p>0.05) sampled 2004–2009. Pie charts indicate the taxonomic families composing four communities that had the largest number of sites. N = number of sample sites comprising each fish community.

Because the dates of the three RUSALCA cruises were not the same in each year, we gathered a broader seasonal perspective on ichthyoplankton abundance. The unfortunate consequence of this timing is that interpretation of the interannual aspect of these three ichthyoplankton collections is confounded by differences in date. Distinct ichthyoplankton species assemblages observed during the August 2004 cruise were associated with different water masses (n=498 larvae at 18 stations). The few planktonic fishes collected during September 2009 (n=22 larvae at 31 stations) were insufficient to make definitive statements about assemblages. At-sea observations of ichthyoplankton in August–September 2012 indicated a much larger number of larval fishes than in 2009. In addition to the RUSALCA cruises, a 60 cm bongo with 0.505 mm mesh net towed at 1.5–2 kts collected ichthyoplankton during our other recent surveys of the Chukchi (2007, 2008, 2012) and Beaufort (2008, 2011) seas. Distinct ichthyoplankton species assemblages observed during the 2004 cruise were associated with different water masses (Norcross et al. 2010), however too few larval fishes were caught during 2009 to make definitive statements about summer ichthyoplankton assemblages in the Chukchi Sea.

We recommend using the same type of gear to produce consistent measures of abundance for a long-term time series. In addition to using a 60 cm bongo net with 0.505 mm mesh, we suggest that future surveys of ichthyoplankton during late summer in the Arctic also sample with a 2–3 mm mesh Methot net towed at a faster speed (3 kts). The larger meshed net may be more effective at catching larger planktonic larval and juvenile fish during late summer (September) in the Chukchi Sea. Starting with its use in the RUSALCA-2004 collections, the 3 m plumb staff beam trawl we employed has become the most widely used and commonly accepted bottom trawl gear in the Chukchi Sea, with relatively dense sampling in the eastern Chukchi and U.S. Beaufort seas, and broad geographic coverage of samples in the Russian western Chukchi. Survey continuity over this large geographic area is an excellent baseline for long-term abundance analyses of demersal fishes.

Though we hypothesized that climate change, specifically a reduction of sea ice cover in the northern Bering and Chukchi Seas, would alter the species composition, abundance and distribution of fishes, we were unable to address this hypothesis with the addition of samples collected in 2009 alone. The timing of the cruises was not the same in 2004 and 2009, thus confounding our analysis of fish distribution in relation to water masses. From 1959–2009, four bottom water masses were distinguished (Alaska Coastal Water, Bering Sea Water, Winter Water, and

Resident Chukchi Water), but all were not found in each year. Water masses and their characteristics vary interannually and seasonally, i.e., the ranges of temperature and salinity values that determined the water mass potential densities were not static. The dominant species differed among collections with place and time. Therefore, changes in distribution of individual fish species, as might be expected with influences of climate change such as reduced ice coverage, could restructure the species composition and spatial extent of fish assemblages.

Sample size in the Chukchi Sea was increased by combining 17 stations in RUSALCA-2004 with 31 stations in RUSALCA-2009; the larger sample size clarified patterns of fish communities. Samples from the RUSALCA-2012 cruise will provide a good complement to the larval and small demersal fishes sampled during the 2004 and 2009 cruises, as we were able to repeat a core group of stations (time-series) as well as increase geographic coverage by adding new stations.

Students

Christine Gleason (M.S. student, Fisheries Oceanography, graduated summer 2012) developed her thesis research based on specimens she collected during the September 2009 RUSALCA cruise. Her thesis examines the correlation of environmental and physiological variables to trace element signatures recorded in fish otoliths and seawater. Although Gleason's graduate stipend was not funded under this CIFAR grant, the grant supported her for four weeks of research specific to the CIFAR project.

This RUSALCA research has provided on-the-job training for 12 UAF student technicians. All technicians have assisted with weighing and measuring fishes, removing otoliths and other tissues, recording data, and computer data entry. Some technicians also have performed the more skilled tasks of assigning ages to otoliths and using sophisticated equipment to determine the trace element content of fish tissues. These 8 students were employed while seeking a B.S. in Fisheries: Keegan Birchfield, Michael Courtney, Thomas Foster, Benjamin Gray, Casey McConnell, Tyler Ray, Matthew Robinson, and Andrea Ruby. Crystal Cano is a student seeking a B.S. in Biology. Brian Perttu was an M.S. student in Geology. Casey Peterson and Peter Reed were pursuing B.A.s in Accounting.

Outreach

- We hosted several outreach events for high school students at the Fisheries Oceanography Laboratory at UAF, and guided them in hands-on activities of fish dissection, microscopic examination of otoliths, and assigning ages based on patterns of dark and light bands in the otoliths. These events included UAF's first Campus Research Day, held on 9 April 2010.
- Morgan Busby gave a NOAA laboratory tour with hands-on activities for visiting MIMSUP (Multicultural Initiative in the Marine Science: Undergraduate Participation) students on 10 March 2011.
- Busby, M.S. 2009. RUSALCA Chukchi Sea Cruise. In: AFSC Quarterly Research Reports, Oct-Nov-Dec 2009. http://www.afsc.noaa.gov/Quarterly/ond2009/divrptsRACE7.htm
- Norcross, B.L., B.A. Holladay, L. Edenfield and C. Gleason. 2011. Chukchi Sea Environmental Studies Program: Fisheries Ecology, Olgoonik-Fairweather debrief meeting, January 2011, Anchorage, Alaska.
- Gleason, C. 2010. Fisheries as a career in Alaska. Middle and High school presentation, November 2010, Grayling, Alaska.

Publications, conference papers, and presentations (Including Literature Cited [superscripts])

Non-peer reviewed publication

[1]Norcross, B.L., B.A. Holladay and C.W. Mecklenburg. 2012. Recent and Historical Distribution and Ecology of Demersal Fishes in the Chukchi Sea Planning Area. Final Report to the Coastal Marine Institute, Task Order M07AC12462, OCS Study BOEM 2012-073, Fairbanks, Alaska.

Oral presentations

Norcross, B.L., B.A. Holladay, C.W. Mecklenburg and C. Gleason. 2010. RUSALCA 2004 and 2009: epibenthic fish distribution in the Chukchi Sea. RUSALCA Summit, October 2010, Kotor, Montenegro.

Carroll, S.S., L. Dehn and B.L. Norcross. 2011. What's in the mix: treatment of ice-seal prey sources within stable isotope mixing models. Alaska Marine Science Symposium, January 2011, Anchorage, Alaska.

Norcross, B.L. and B.A. Holladay. 2011. 50 years of demersal fishes in the Chukchi Sea. Alaska Marine Science Symposium, January 2011, Anchorage, Alaska.

Norcross, B.L., B.A. Holladay and C.W. Mecklenburg. 2011. Distribution and ecology of demersal fishes in the Chukchi Sea over 50 years. Arctic Frontiers Conference, January 2011, Tromso, Norway. (Invited talk.)

Gleason, C. 2011. Otolith chemistry of Arctic cod and Arctic staghorn sculpin in the Chukchi Sea. Rasmuson Fellows annual meeting, March 2011, Anchorage, Alaska.

Gleason, C. and B.L. Norcross. 2012. Otolith chemistry of Arctic cod, Arctic staghorn sculpin, and Bering flounder in the Chukchi Sea. American Fisheries Society Meeting, Alaska Chapter, November 2011, Girdwood, Alaska.

[2]Norcross, B.L., B.A. Holladay and C. Gleason. 2012. Fish ecology – Baseline for assessing effects of climate change on fishes. RUSALCA PI Meeting, March 2012, Miami, Florida.

Norcross, B.L., B.A. Holladay, M. Busby and C.M. Gleason. 2013. Small demersal fishes and ichthyoplankton: Ecology and community structure. RUSALCA PI Meeting, May 2013, St. Petersburg, Russia.

Poster presentations

Busby, M.S., B.L. Norcross and B.A. Holladay. 2013. Ichthyoplankton collected on the 2004 and 2009 Russian-American Long-Term Census of the Arctic research cruises. 28th Lowell Wakefield Fisheries Symposium: Responses of Arctic Marine Ecosystems to Climate Change. Anchorage, AK, March 2013.

Norcross, B.L., B.A. Holladay and C.W. Mecklenburg. 2013. Richness and diversity of demersal fishes in the eastern Chukchi Sea over 50 years. 28th Lowell Wakefield Fisheries Symposium: Responses of Arctic Marine Ecosystems to Climate Change. Anchorage, AK, March 2013.

Peer-reviewed publication published during this funding period but arising from support to this project under the previous cooperative agreement NA17RJ1224

Norcross, B.L., B.A. Holladay, M.S. Busby and K.L. Mier. 2010. Demersal and larval fish assemblages in the Chukchi Sea. *Deep-Sea Research II*, 57:57–70.

The Pacific Gateway to the Arctic—Quantifying and understanding Bering Strait oceanic fluxes

Thomas Weingartner, PI
Terry Whitledge, PI
University of Alaska Fairbanks

CIFAR theme: Ecosystem Studies & Forecasting

NOAA Goals: Healthy Oceans; Climate Adaptation & Mitigation

NA08OAR4320870 Amendments 5 & 7 NOAA Office: OAR-CPO, Kathleen Crane, Sponsor
Although this project was reviewed and competitively awarded with the other RUSALCA projects, it was funded jointly by NSF and NOAA, with NSF covering year 1.

Primary objectives

- Provide mooring instrumentation and flotation for 4 complete moorings and recover the same;
- Provide CTD (conductivity, temperature, depth) data collection and analyses for stations occupied during the mooring deployment and recovery cruises;
- Collect and analyze nutrient data collected for stations occupied during the mooring deployment and recovery cruises;
- Assist in mooring data quality control, archiving and analysis;
- Provide a better understanding of the variability and causes of mass, heat, and freshwater transports through Bering Strait.

Approach/methodology

Our approach involved making measurements of the salinity, temperature, velocity, fluorescence, and nitrate in the western channel of Bering Strait at hourly intervals for a period of one year for each field year of the program. The measurements were made from four moorings deployed across the western channel of Bering Strait. Each mooring contained an RDI 307 kHz upward looking ADCP (Acoustic Doppler Current Profiler) current meter for measuring velocity (or a single-point velocity measurement from an Aanderaa acoustic current meter) and a SeaCat (SBE-16 T/C recorder or SBE-37 MicroCat) for the temperature and salinity measurements. The mooring in the center of the strait includes a fluorometer and a nitrate sensor. We are also engaged in analyzing the data from these moorings and the CTD section in conjunction with a 4 mooring array deployed in the eastern (US EEZ) channel of Bering Strait with Rebecca Woodgate of the University of Washington.

Research accomplishments/highlights/findings.

1. An early finding in this project was that the record 2007 Arctic Ocean sea ice retreat was accompanied by record-length (1991–2007) highs in mean annual transport and temperature in Bering Strait. In 2007, heat fluxes were 5–6×10^{20}J/yr, nearly twice the heat flux estimated for 2001, and comparable to the annual shortwave radiative flux into the Chukchi Sea. The mean annual heat flux through the Strait increased nearly monotonically from 2001 to 2007. The 2007 heat flux was sufficient to melt 1.8×10^{6} km^2 of 1-m-thick ice in that year. We suggested that the Bering Strait inflow influences sea-ice by providing a trigger for the onset of solar-driven melt, a conduit for oceanic heat into the Arctic, and (due to long transit times) a subsurface heat source within the Arctic in winter. A crucial finding was that this substantial interannual variability was due to temperature and transport changes. The transport variability was due to local winds and, significantly, by apparent variability (> 0.2Sv equivalent) in the Pacific-Arctic pressure-gradient that forces the along-strait flow (Woodgate et al., 2010).
2. The Alaskan Coastal Current, which is confined to the eastern (US EEZ) side of Bering Strait contributes about 33% of the heat and 25% of the freshwater fluxes through Bering Strait (Woodgate et al., 2006), and the re-designed mooring array partially supported by NOAA has helped to refine these estimates through time.
3. More recently we found that the Bering Strait mean annual transport increased by ~50% from 2001 (~0.7Sv) to 2011 (~1.1Sv), driving heat and freshwater flux increases. About 67% of the transport increase was due to an increase in the Pacific-Arctic pressure-head, while the remainder of the increase was attributable to a decrease in the local winds. The 2011 heat flux (~5×10^{20}J) was similar in magnitude to the previous record high (2007)

due to transport increases and warmer lower layer (LL) temperatures, despite sea surface temperature (SST) have cooled. In the last decade, warmer LL waters arrived earlier (1.6±1.1 days/yr), though winds and SST were typical for recent decades. Maximum summer salinities, likely set in the Bering Sea, remain remarkably constant (~33.1psu) over the decade, elucidating the stable salinity of the western Arctic cold halocline. Despite this, freshwater flux variability (strongly driven by transport) exceeds variability in other Arctic freshwater sources. Our result indicate that remote data (winds, SST) are not sufficient for quantifying variability, indicating that documenting interannual variability can only be assessed by *in situ* year-round measurements.

4. More recently we have been investigating causes of interannual variability using a variety of data sets (satellite-altimeter, ARGO profiling floats, as well as the Bering Strait measurements) and simple, barotropic numerical models. Danielson et al. (in prep) show that Bering Strait transport variability is a function of both wind stress curl variations over the Bering Sea basin and northward-propagating shelf waves generated over the Bering shelf. The former operates over seasonal and longer time scales and influences the Pacific-Arctic pressure gradient primarily due to variations in Ekman pumping (and the associated dynamic height field) over the Bering Sea and Western Subarctic Gyre. Changes in this pressure gradient account for ~50% of the annual mean transport variability between 1997 and 2011. In particular a reduction in wind stress curl over the Bering Sea basin was associated with enhanced northward heat transport through Bering Strait in 2007 and 2011. By including remote wind forcing over the Bering Sea continental shelf (as a proxy for shelf waves) in conjunction with local winds over Bering Strait, we can account for 60% and 80% of the subtidal Bering Strait transport variance in summer and winter, respectively. By contrast, local winds alone account for ~25% and ~50% of the summer and winter transport variance, respectively.
5. We have also been using a regional ocean configuration of the MITgcm (MIT General Circulation Model), and extracting vertical sections (18 km horizontal and 10 m vertical resolution) that correspond to existing moorings in the Bering Strait. This is a more sophisticated model than that used by Danielson et al. (discussed above) in that is a global model that includes baroclinicity. Direct comparison between the model and the moorings show reasonably good agreement with similar seasonality as indicated by the Taylor diagrams in Figure 1. Calculations of the modeled long term mean velocity across a section including the Alaska Coastal Current (ACC) closely matches previously published data made at a single point (the A3 mooring) that does not include the ACC. The modeled Bering Strait yields an estimated mean annual northward Strait transport of 1.1Sv. This suggests that 33% of the Strait transport is excluded by omitting the ACC. As suggested by the observations, the model also indicates that anomalies in northward heat transport are established by anomalies in both the transport and temperature (Figure 2). The sources of these anomalies are the subject of continuing investigation.

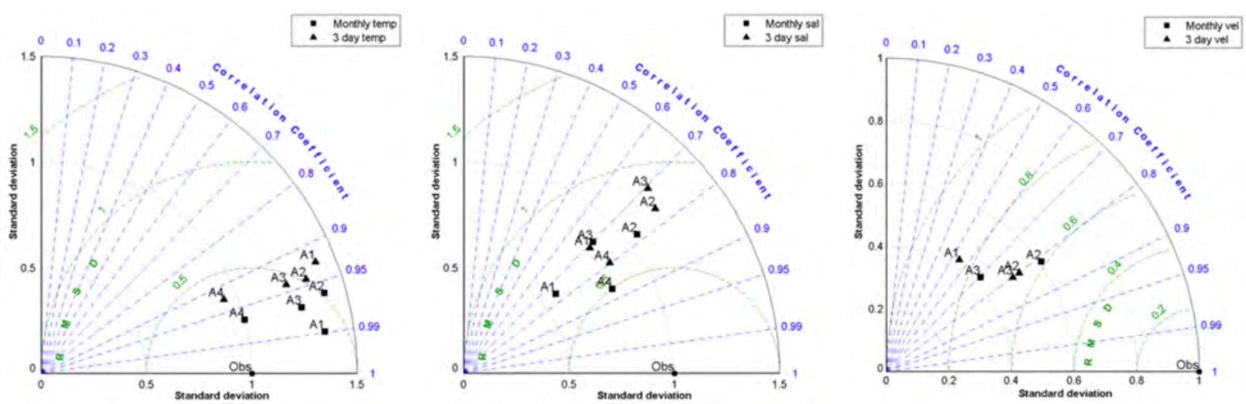


Figure 1. Taylor diagrams for temperature (left), salinity (middle) and velocity (right). Observations (●) are normalized so that STD = 1, RMSD = 0, r = 1 for all moorings, and compared to modeled monthly average output (■) and 3 day average output (▲).

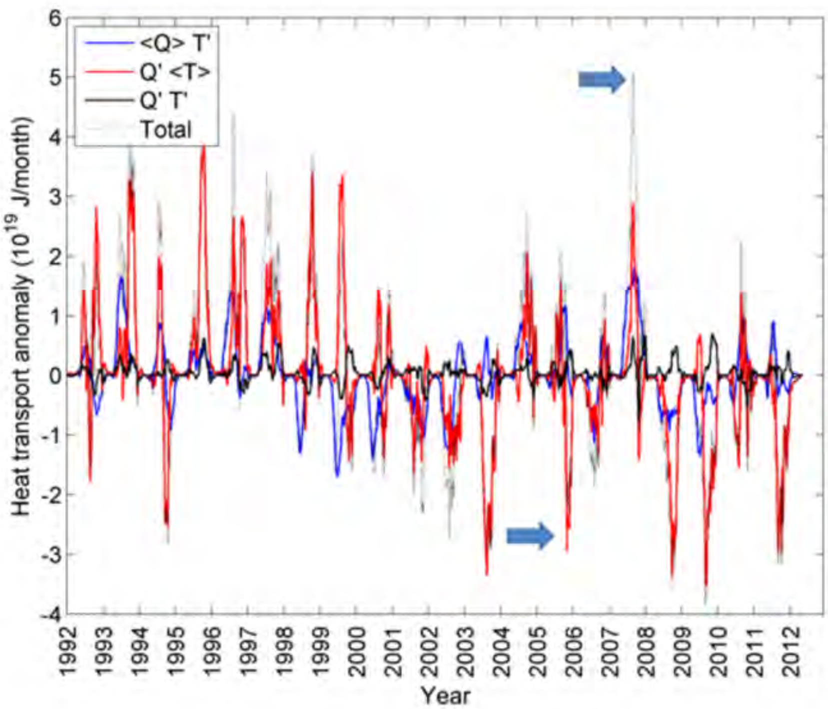


Figure 2. Reynolds decomposition of Bering Strait heat flux. The blue line shows the contribution of heat content anomaly to heat content, the red line shows contribution of volume transport anomaly, the black line shows the product of the anomalies, and the gray line shows the sum of all contributions. Extremely anomalous heat transport events are shown by horizontal arrows.

6. We have collected six years (2005–2011) of nitrate data from these moorings, although the instrument failed during the 2008–2009 deployment period. In aggregate these data provide a description of the annual cycle of nitrate concentrations (and fluxes) through Bering Strait (as illustrated in Figure 3). As a general rule low nitrate coincides with low-salinity waters and high nitrate concentrations are associated with high salinity waters. Hence low nitrate values are generally observed in fall due to vertical mixing of low-nitrate and dilute surface waters with high-nitrate and more saline waters at depth. These data, along with those from the east side of the strait, are being combined to estimate interannual variability in nitrate fluxes through Bering Strait.

NOAA relevance/societal benefits

Bering Strait is the sole connection between the Pacific and Arctic oceans. Given the significant role of Pacific waters in the Arctic, quantifying the Bering Strait through flow and its properties is essential to understanding the present functioning of the Arctic system, and the causes and prediction of present and future Arctic change.

Education

Michael Kong, a Ph.D. student in chemical oceanography, assisted with CTD data collection, nutrient sampling and analyses. Seth Danielson, a Ph.D. student in physical oceanography, analyzed CTD data, and after completing his Ph.D., continued additional analyses over the Bering and Chukchi seas, which included Bering Strait. Undergraduate student Kevin Taylor assisted with mooring design, fabrication, deployment, recovery, and instrument handling. Chase Stoudt, an M.S. student in physical oceanography, assisted in the work at sea. Jonathan Whitefield, a Ph.D. student in physical oceanography, assisted in the fieldwork and is comparing the observations with the MITgcm ECCO model data.

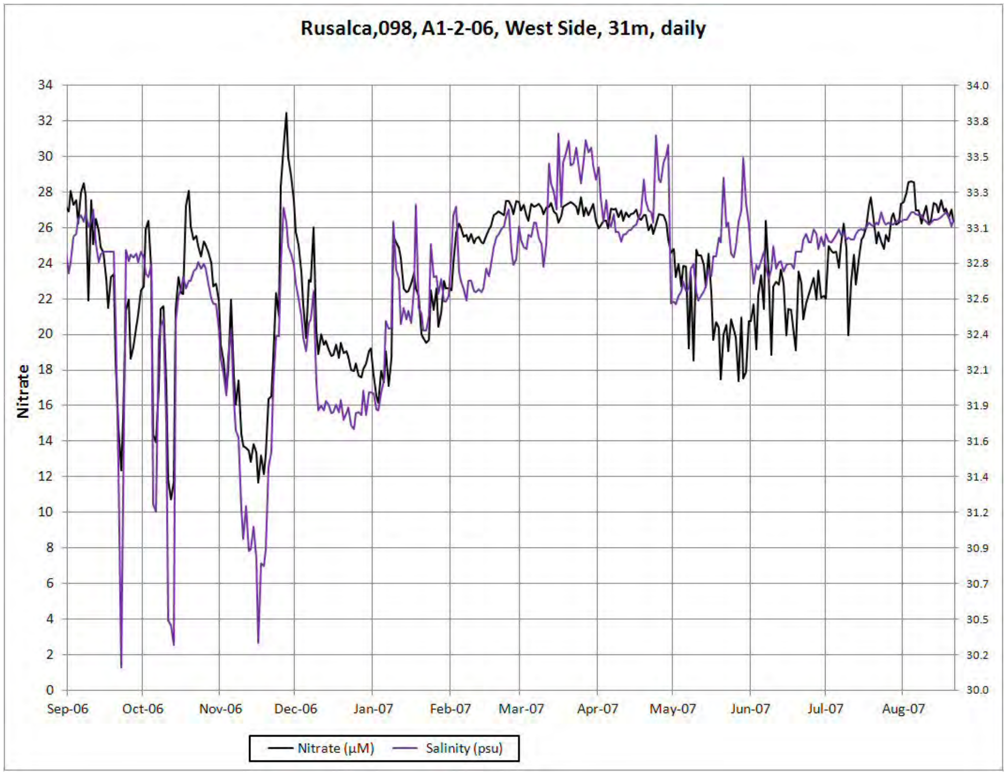


Figure 3. Time series of salinity (black) and nitrate (blue) from the mooring in the western channel of Bering Strait for the period of September 2006–August 2007.

Outreach

We contribute to a project website hosted at the University of Washington: http://psc.apl.washington.edu/HLD/. T. Weingartner is planning to attend the "Indigenous Knowledge of Ocean Currents Workshop", tentatively planned for December 2013 in Nome, Alaska. He will present results from this NOAA activity at that workshop.

Publications, conference papers, and presentations

Peer-reviewed publication

Woodgate, R.A., T.J. Weingartner and R. Lindsay. 2012. Observed increases in Bering Strait oceanic fluxes from the Pacific to the Arctic from 2001 to 2011 and their impacts on the Arctic Ocean water column. *Geophysical Research Letters* 39, L24603, doi:10.1029/2012GL054092.

Publications under preparation

Danielson, S., T. Weingartner, K. Hedstrom, K. Aagaard, R. Woodgate, E. Curchitser and P. Stabeno. Ekman transport, continental shelf waves, and variations of the Pacific-Arctic sea surface height gradient: Coupled wind-forced controls of the Bering-Chukchi shelf circulation (undergoing internal review, submittal to JGR expected in September 2013).

Whitefield, J., P. Winsor, T. Weingartner and R. Woodgate. Extreme Bering Strait transport events in a global ocean model (in preparation, anticipated submittal to JGR in December 2013).

Oral presentations

Whitefield, J., P. Winsor and T. J. Weingartner. 2012. Bering Strait throughflow from a global ocean model. Alaska Marine Science Symposium, January 2012, Anchorage, Alaska.

Whitefield, J., P. Winsor and T.J. Weingartner. 2012. Using in situ observations to validate the performance of a high-resolution global model in the Bering, Beaufort and Chukchi Seas. ECCO2 meeting, NASA/JPL, Pasadena, CA, 31 October–2 November 2012.

Woodgate, R., R. Lindsay, T. Weingartner, T. Whitledge, E. Bondareva, M. Kulakov and V. Golavsky. 2013. Bering Strait, February 2013 update. Distributed Biological Observatory Meeting, Seattle, WA, February 2013.

Poster presentations

Whitefield, J., P. Winsor and T. J. Weingartner. 2012. Bering Strait throughflow from a global ocean model. AGU-ASLO Ocean Sciences Meeting, February 2012, Salt Lake City, Utah.

Whitefield J., Winsor P., Weingartner T.J. Using in situ observations to validate the performance of a high-resolution global model in the Bering, Beaufort and Chukchi Seas. 16th Arctic Ocean Model Intercomparison Project, Woods Hole, MA, 23–26 October 2012.

Whitefield, J., P. Winsor and T.J. Weingartner. 2013. Using in situ observations to validate the performance of a high-resolution global model in the Bering, Beaufort and Chukchi Seas. Alaska Marine Science Symposium, Anchorage, AK, 21–25 January 2013.

Whitefield, J., P. Winsor and T.J. Weingartner. 2013. Transport and T/S variability in Bering Strait from a global ocean model and a shipboard survey. Gordon Research Conference on Polar Marine Science, Ventura, CA, 10–15 March 2013.

Reference (publication from earlier RUSALCA work)

Woodgate, R.A., K. Aagaard and T.J. Weingartner. 2006. Interannual changes in the Bering Strait fluxes of volume, heat and freshwater between 1991 and 2004. *Geophysical Research Letters*, 33, L15609, doi:10.1029/2006GL026931.

Peer-reviewed publication published during this funding period but arising from support to this project under the previous cooperative agreement NA17RJ1224

Woodgate, R. A., T. Weingartner and R. Lindsay. 2010. The 2007 Bering Strait oceanic heat flux and possible relationships to anomalous Arctic Sea Ice Retreat. *Geophysical Research Letters*, 37, L01602, doi:10.1029/2009GL041621.

Partner organizations and collaborators

State Research Navigational Hydrographic Institute of the Russian Federation: Expedition logistics and coordination (In-kind support, facilities)

Group Alliance (Russia): logistics and translation services (In-kind support, facilities)

Arctic and Antarctic Research Institute (Russian Federation): moorings and CTD (Collaborative Research)

Polar Science Center, Applied Physics Lab, University of Washington (Rebecca Woodgate), Co-PI, Co-Chief Scientist, moorings, CTD, physical oceanography (Collaborative Research)

Alaska Ocean Observing System (AOOS) provided some of the mooring equipment used in this project.

Changes/problems/special reporting requirements

No problems in reaching milestones, although there were intermittent delays over the course of the project pertaining to data delivery delays (from Russia) and delays in obtaining access to the western channel of Bering Strait. These delays were detailed in prior reports and are not repeated here. We note that they did not affect the net outcome of the project.

RUSALCA: Global change in the Arctic: Interactions of productivity and nutrient processes in the northern Bering and Chukchi Seas

Terry E. Whitledge, PI
Dean A. Stockwell, co-PI
University of Alaska Fairbanks

CIFAR theme: Ecosystem Studies & Forecasting

Other investigators/professionals associated this project:
Daniel Naber*, University of Alaska Fairbanks*

NOAA Goals: Healthy Oceans; Climate Adaptation & Mitigation

NA08OAR4320870 Amendment 4, 6, 12 &16 NOAA Office: OAR-CPO, John Calder/Kathleen Crane, Sponsor

Primary objectives

We are using measurements of nutrient and plant pigment distributions, phytoplankton taxonomy, and rates of primary productivity to assess changes in the carbon cycle related to nutrient utilization and primary production that may be driven by variations in the Arctic climate.

Research accomplishments/highlights/findings

- The major RUSALCA climate change cruises in the Chukchi Sea that emphasized biological, chemical, geological and physical oceanography occurred aboard the R/V *Professor Khromov* in late summer of 2009 and 2012. In 2010 and 2011 additional samples were collected for nutrients (nitrate, nitrite, ammonium, phosphate and silicate) and chlorophyll for a total of approximately 400 station locations. More than 2000 samples have been analyzed to date. In addition, during these four years, *in situ* primary production rate measurements were made using carbon and nitrogen isotopes at 6 light depths on waters from 52 stations.

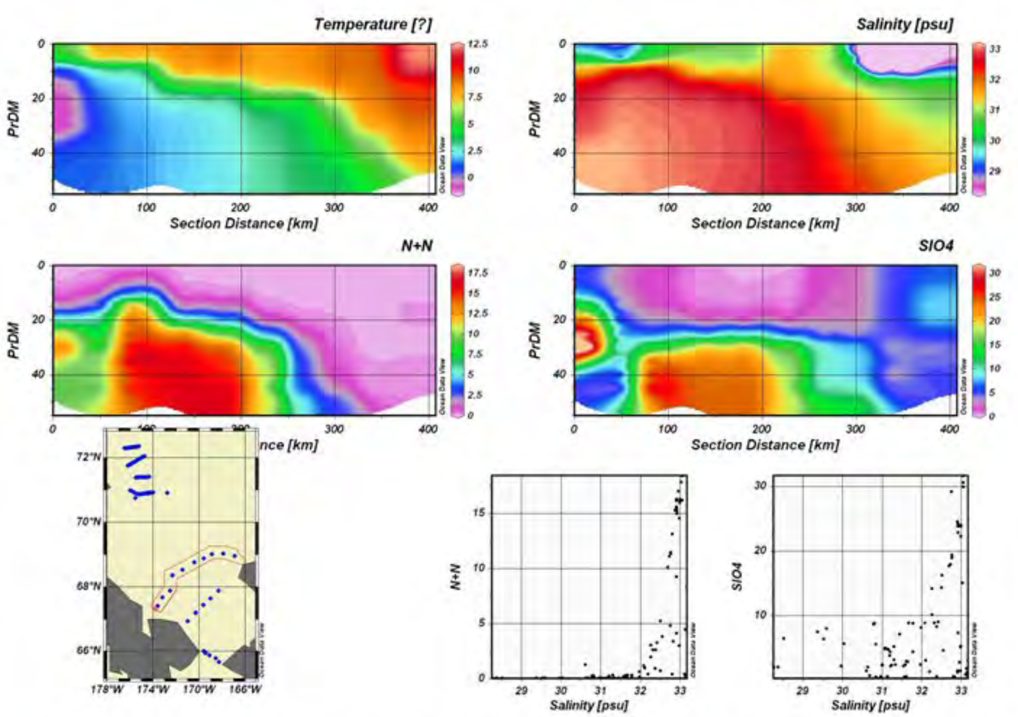


Figure 1. Typical distributions of temperature (degC), salinity, nitrate (N+N) and silicate (SiO_4) across the central Chukchi Sea in 2009. PrDM=pressure depth in meters. Nutrient units are µmole/liter.

- Strong horizontal gradients in nutrient concentrations of nitrate plus nitrite (N+N) and silicate (SiO_4) are observed across all sections across the Chukchi Sea from the low salinity Alaska Coastal Water (ACW) on the

U.S. side to the relatively high salinity water Anadyr Water (AW) in the Russian EEZ (Figure 1). Repeated transects show that the nutrient gradients change over time in response to variations in wind mixing, currents and freshwater discharge change over the summer season but nevertheless an approximate hundred-fold spatial gradient in nutrient concentrations is maintained. The vertical concentrations of nutrients are often depleted throughout the water column in ACW while vertical stratification remains strong and nutrient concentrations remain high in AW.

- Nutrient and chlorophyll concentrations determined by hydrographic data transects and moored instrumentation in Bering Strait both vary widely on a temporal basis. Shipboard measurements are collected only during the warm seasons, while moored In Situ Ultraviolet Spectrometers (ISUS) and fluorometers collect data records for periods of 1 to 2 years. The observed range of nitrate from the Bering Strait moorings from 2005–2007 (Figure 2) was 8–32 µmoles/liter over the seasons while chlorophyll concentrations ranged from zero in winter to approximately 14 µg/liter in the summer. It is also evident from the mooring records that a large amount of mesoscale and higher frequency variations occur. Ultimately both the shipboard transects and the mooring records will be used to assess whether there are decadal trends in nitrate and chlorophyll concentrations. When only the shipboard observations are used, the decadal concentrations of nutrients and chlorophyll appear to have declined about 30% but the horizontal and vertical variability are large enough to cast doubt on these estimates.

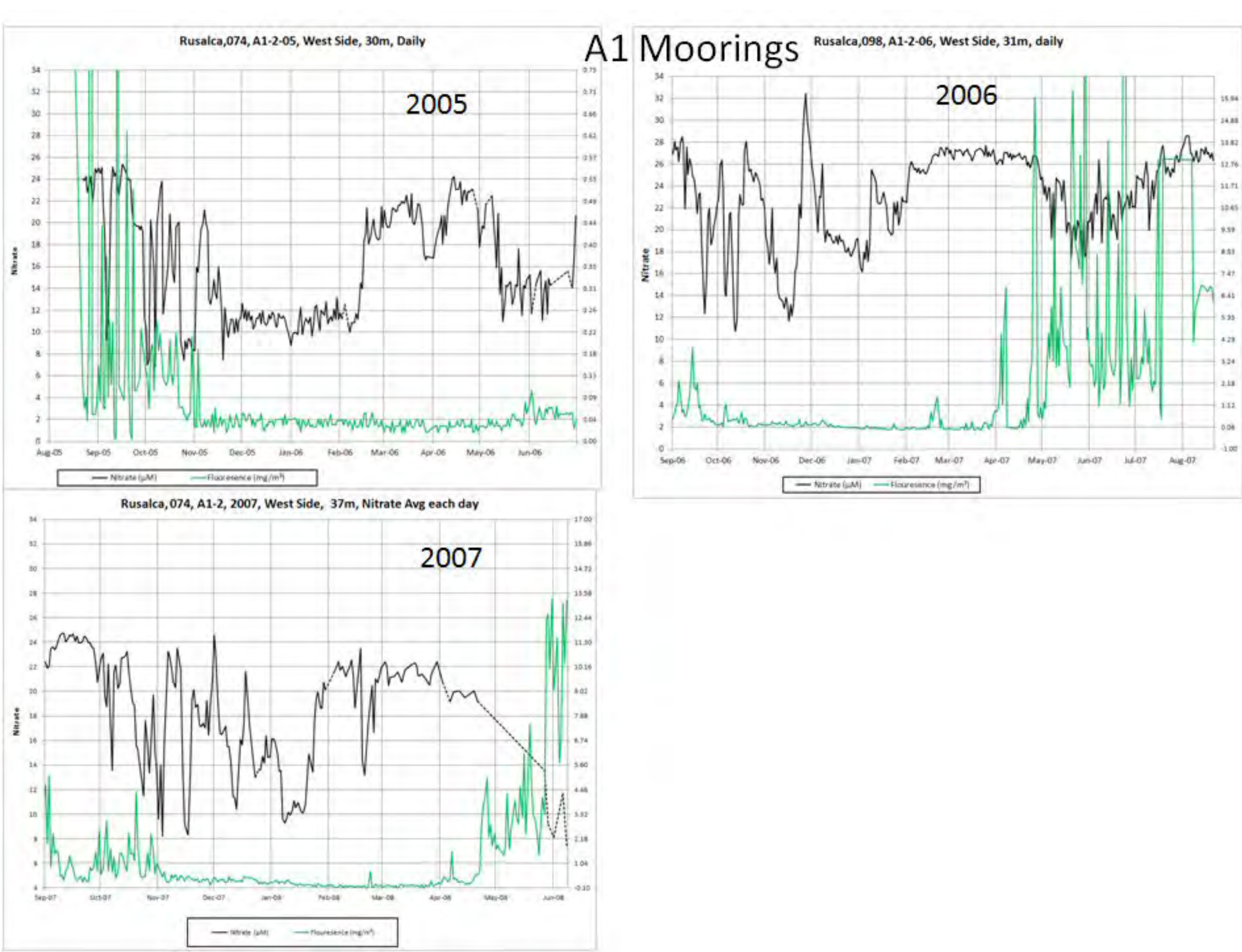


Figure 2. Nitrate (black; µmole/liter) and chlorophyll (green; µg/liter) concentrations for 2005–2007 at A1 mooring location in western Bering Strait within the Russian EEZ.

- A pan-Arctic assessment of nutrient fluxes was conducted with colleagues Torres-Valdes et al. (2013) with physically based mass-balance transport estimates from Bering Strait, Davis Strait, Fram Strait and Barents Sea output using an inverse model-generated velocity field in combination with a quasi-synoptic assemblage of hydrographic and hydrochemical data. It was found that the most important imports of nitrate and phosphate were from the Barents Sea opening while the most important import of silicate was from Bering Strait. The

Arctic Ocean was found to be a net exporter of silicate and phosphate to the North Atlantic. The phosphate export is almost twice as large as previous estimates.

- In collaboration with a former student, Sang Lee, composition and abundance of phytoplankton in the Chukchi Sea were assessed on the major biological cruises in 2009 and 2012. It was found that the two main water masses were dominated by different phytoplankton communities. The ACW had a much larger percentage of small phytoplankton (<20µm) compared to the AW with higher concentrations of large phytoplankton (>20µm). Even within the smaller phytoplankton communities the species composition varied and some warmer water species like Synechococcus sp. and Prochlorococcus sp. were observed in unusually large numbers probably as a result of the recently warm surface waters (Figure 3).

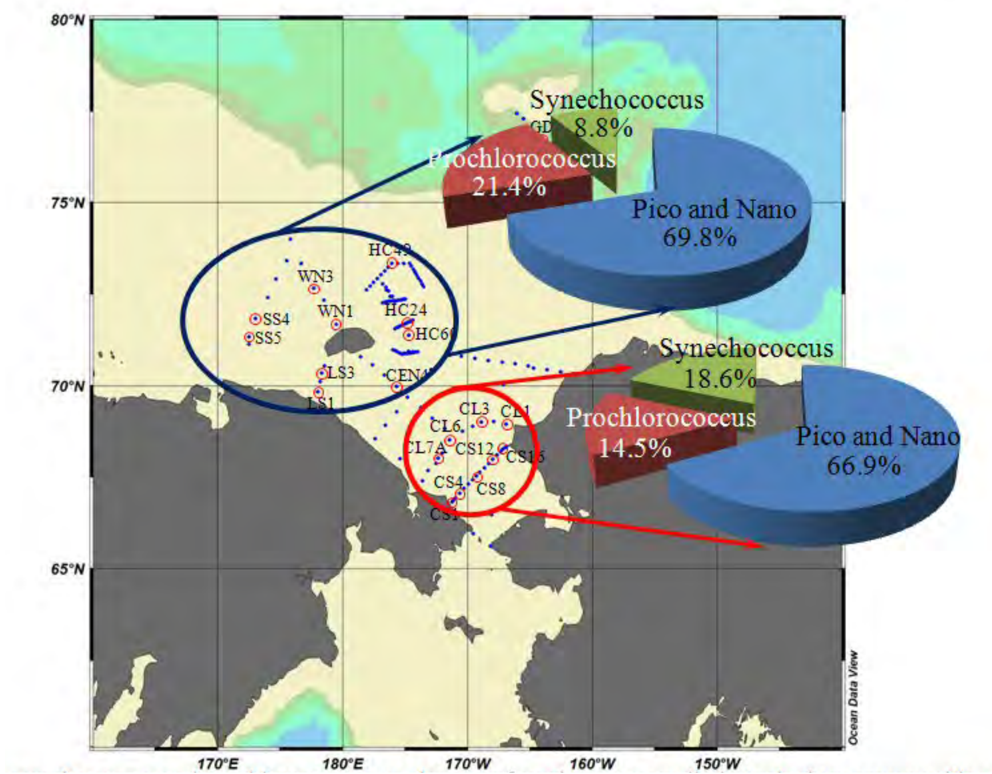


Figure 3. In 2009, an unusually large number of warm water synechococcus *and* prochlorococcus *species were found among small phytoplankton (<20 µm) in our study sites.*

- Recent estimates of rates of primary production in 2009–2012 indicate a possible decline of 2–3 fold compared to the 1980s (Figure 4) and at the same time smaller size classes appear to have increased, and integrated chlorophyll biomass decreased by 40%. To explain these observations, it is hypothesized that large phytoplankton are growing fast enough to reduce the nutrient concentrations to low levels while the zooplankton in the relatively warm water are grazing the large cells leaving a large fraction of the small phytoplankton cells. Low chlorophyll values represent the remains from the grazing pressure and the relatively low phytoplankton biomass produces the small primary production rates.

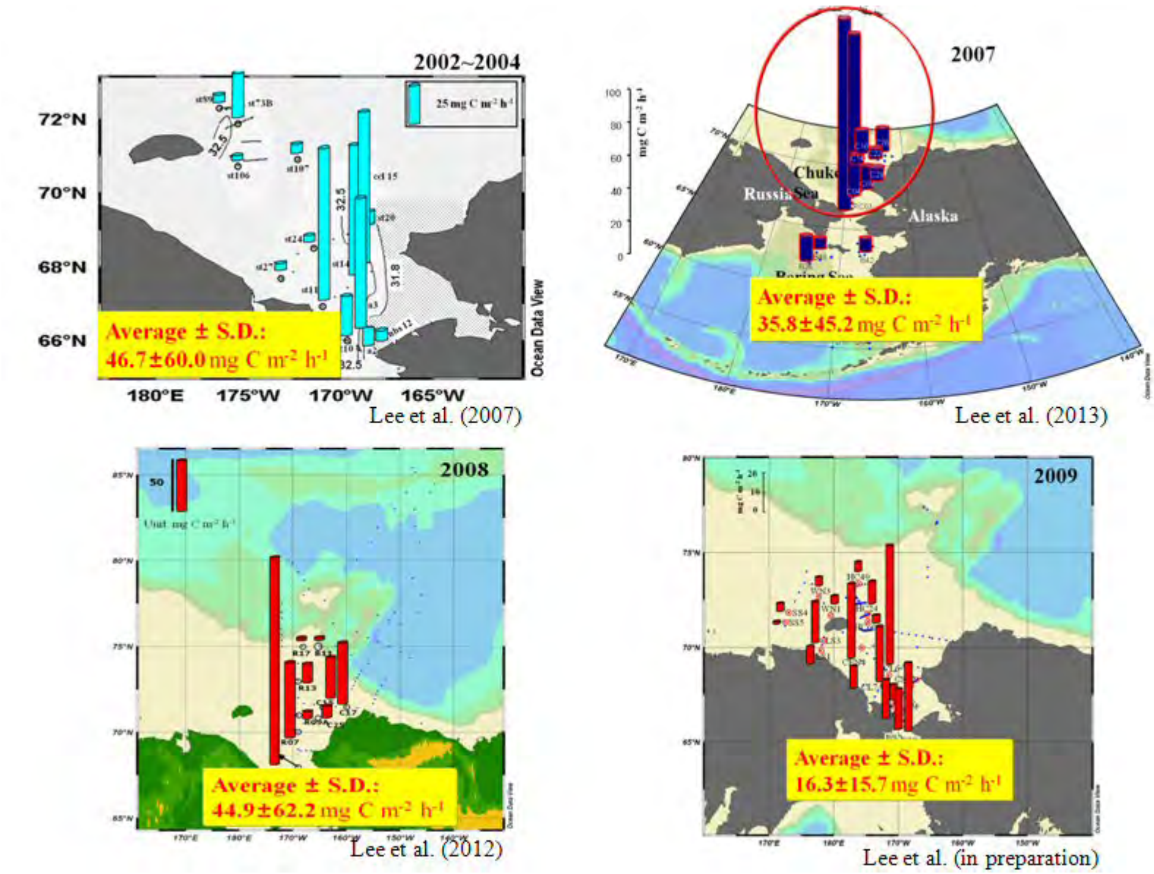


Figure 4. Recent estimates of rates of primary production in 2009–2012 indicate a possible decline of 2–3 fold compared to the 1980s.

NOAA relevance/societal benefits

This project continues to determine the amount of nutrients that are available to support primary production in the seasonally ice-covered waters of the Chukchi Sea for comparison with data collected over the prior two decades to assess changes that are related to climate change.

Education

Michael Kong, a student enrolled in the Ph.D. program in Oceanography, participated in the RUSALCA cruises in 2009–2012 as a part of his graduate research program investigating primary production processes in ice-covered seas and received support from this project for his field and laboratory studies.

Outreach

- Public outreach was carried out in Nome at the start of the cruise in August 2011 with help from Gay Sheffield, the Alaska Sea Grant Marine Advisory Program agent in Nome.
- Whitledge made a presentation ("Cooperative research programs with Russian scientists and a new research vessel to support field research") to the Northern (Arctic) Federal University, Arkhangelsk, Russia delegation, in Fairbanks on 4 April 2011.
- Data from prior RUSALCA sampling has been placed on the SFOS ftp site (ftp://ftp.sfos.edu/terry/rusalca) for use by other project PIs and the RUSALCA data management project.

Publications and conference presentations

Oral presentations

Lee, S.H., K.H. Chung and T.E. Whitledge. 2011. Phytoplankton and ice algae communities responding to the environmental changes in the western Arctic Ocean. Presented at Arctic Science Summit Week Symposium, 27 March–1 April 2011, Seoul, Korea.

Longina, E.A., T.V. Matveeva, V.I. Petrova, D.A. Korshunov, V.A. Gladysh, K. Crane, T. Whitledge and G.A. Cherkashov. 2010. Did pockmark-like structures from the Chukchi Sea form due to fluid discharge? Presented at 10th International Conference on Gas in Marine Sediments, 6–12 September 2010, Listvyanka, Russia.

Whitledge, T.E. 2010. RUSALCA program overview. RUSALCA PI Meeting, 9–12 October 2010, Kotor, Montenegro.

Whitledge, T.E. 2010. Nutrients, chlorophyll and primary productivity during the 2009 RUSALCA Cruise. RUSALCA PI Meeting, 9–12 October 2010, Kotor, Montenegro.

Whitledge, T.E. and Sang H. Lee. 2012. Fluxes and change detection in nutrients, chlorophyll, phytoplankton composition and primary production. RUSALCA PI Meeting, 10–12 March 2012, Miami, Florida.

Peer-reviewed publications published during this funding period but arising from support to this project under the previous cooperative agreement NA17RJ1224

Lee, S.H., M. Jin and T.E. Whitledge. 2010. Comparison of bottom sea ice algal characteristics from coastal and offshore regions in the Arctic Ocean. *Polar Biology*, 33:1331–1337.

Lee, S.H., D.A. Stockwell and T.E. Whitledge. 2010. Uptake rates of dissolved inorganic carbon and nitrogen by under-ice phytoplankton in the Canada Basin in summer 2005. *Polar Biology*, 33:1027–1036.

Pickart, R.S., L.J. Pratt, D.J. Torres, T.E. Whitledge, A.Y. Proshutinsky, K. Aagaard, T.A. Agnew, G.W.K. Moore and H.J. Dail. 2010. Evolution and dynamics of the flow through Herald Canyon in the western Chukchi Sea. *Deep Sea Research II*, 57:5–26.

Lee, S.H., C.P. McRoy, H.M. Joo, R. Gradinger, X. Cui, M.S. Yun, K.H. Chung, S.H. Kang, C.K. Kang, E.J. Choy, S. Son, E. Carmack and T.E. Whitledge. 2011. Holes in progressively thinning Arctic sea ice lead to new ice algae habitat. *Oceanography*, 24:302–308.

Lee, S.H., H.M. Joo, M.S. Yun and T.E. Whitledge. 2012. Recent phytoplankton productivity of the northern Bering Sea in the western Arctic Ocean during early summer in 2007. *Polar Biology*, 35:83–98, doi:10.1007/s00300-011-1035-9.

Lee, S.H., D.A. Stockwell, H.M. Joo, Y.B. Son, C.K. Kang and T.E. Whitledge. 2012. Phytoplankton production from melting ponds on Arctic sea ice. *Journal of Geophysical Research*, 117, C04030, doi:10.1029/2011JC007717.

Peer-reviewed publications that utilized RUSALCA data, shiptime, and/or scientific collaboration

Purcell, J.E., R.R. Hopcroft, K.N. Kosobokova and T.E. Whitledge. 2010. Distribution, abundance, and predation effects of epipelagic ctenophores and jellyfish in the western Arctic Ocean. *Deep Sea Research II*, 57:127–135. doi:10.1016/j.dsr2.2009.08.011

Walsh, J.J., D.A. Dieterle, F.R. Chen, J.M. Lenes, W. Maslowski, J.J. Cassano, T.E. Whitledge, D. Stockwell, M.V. Flint, I.N. Sukhanova and J. Cristensen. 2011. Trophic cascades and future harmful algal blooms within ice-free Arctic Seas north of Bering Strait: A simulation analysis. *Progress in Oceanography*, 91:312–343, doi:10.1016/j.pocean.2011.02.001

Torres-Valdes, S., T. Tsubouchi, S. Bacon, A. Naveira-Garabato, R. Sanders, B. Petrie, G. Kattner, K. Azetsu-Scott and T.E. Whitledge. 2013. Export of nutrients from the Arctic Ocean. *Journal of Geophysical Research - Oceans*, 118:1625–1644. doi:10.1002/jgrc.20063.

Planned publications

Whitledge participated in the May RUSALCA PI synthesis meeting, where he presented "Change detection in nutrients, chlorophyll, phytoplankton composition and primary production" that was co-authored with Lee, University of Pusan. Whitledge will lead synthesis task 2) Bering Strait fluxes (heat, fresh water, volume, nutrients, migrations of marine life), will co-lead with Grebmeier task 3) Community production, and will participate in task 1) Physical oceanographic observations of Pacific water transport.

Partner organizations and collaborators

A collaborative proposal with Russian colleagues was submitted to the U.S. Civilian Research & Development Foundation to fund additional data analysis and synthesis based on the new cruise data.

Appendix 1
CIFAR RUSALCA Projects Awarded in Cooperative Agreement NA08OAR4320870
1 July 2008 to 30 June 2013

Last	First	Proposal Title	Mod.	Project Budget	Theme Description
Hopcroft	**Russell**	A long term census of Arctic zooplankton communities	1	$149,950	Ecosystem Studies & Forecasting
Hopcroft	**Russell**	A long term census of Arctic zooplankton communities	8	$12,441	Ecosystem Studies & Forecasting
Hopcroft	**Russell**	A long term census of Arctic zooplankton communities	14	$105,367	Ecosystem Studies & Forecasting
Iken	**Katrin**	RUSALCA: Arctic food web structure & epibenthic communities in a climate change context	2	$157,734	Ecosystem Studies & Forecasting
Iken	**Katrin**	RUSALCA: Arctic food web structure & epibenthic communities in a climate change context	9	$38,582	Ecosystem Studies & Forecasting
Iken	**Katrin**	RUSALCA: Arctic food web structure & epibenthic communities in a climate change context	13	$41,520	Ecosystem Studies & Forecasting
Iken	**Katrin**	RUSALCA: Arctic food web structure & epibenthic communities in a climate change context	15	$79,117	Ecosystem Studies & Forecasting
Norcross	**Brenda**	Fish ecology & oceanography: RUSALCA 2008 and 2012	3	$161,033	Ecosystem Studies & Forecasting
Norcross	**Brenda**	Fish ecology & oceanography: RUSALCA 2008 and 2012	10	$65,121	Ecosystem Studies & Forecasting
Norcross	**Brenda**	Fish ecology & oceanography: RUSALCA 2008 and 2012	11	$68,715	Ecosystem Studies & Forecasting
Norcross	**Brenda**	Fish ecology & oceanography: RUSALCA 2008 and 2012	17	$80,062	Ecosystem Studies & Forecasting
Weingartner	**Thomas**	The Pacific gateway to the Arctic—Quantifying and understanding Bering Strait oceanic fluxes	5	$186,052	Ecosystem Studies & Forecasting
Weingartner	**Thomas**	The Pacific gateway to the Arctic—Quantifying and understanding Bering Strait oceanic fluxes	7	$174,316	Ecosystem Studies & Forecasting
Whitledge	**Terry**	Global change in the Arctic: Interactions of productivity and nutrient processes in the northern Bering and Chuckchi Seas	4	$136,827	Ecosystem Studies & Forecasting
Whitledge	**Terry**	Global change in the Arctic: Interactions of productivity and nutrient processes in the northern Bering and Chukchi Seas	6	$34,962	Ecosystem Studies & Forecasting
Whitledge	**Terry**	Global change in the Arctic: Interactions of productivity and nutrient processes in the northern Bering and Chukchi Seas	12	$37,949	Ecosystem Studies & Forecasting
Whitledge	**Terry**	Global change in the Arctic: Interactions of productivity and nutrient processes in the northern Bering and Chukchi Seas	16	$85,137	Ecosystem Studies & Forecasting
		Total projects funded		**$1,614,885**	

Appendix 2. Students supported by CIFAR RUSALCA projects 2008–2013
(Students in **bold green** received greater than 50% full-time equivalent funded from RUSALCA)

Name	Degree Seeking	Hours	Months	Project	Fund	Year*	Status
Courtney, Michael	B.S.	65.5	0.4	RUSALCA-Fish	333702	RY11	
Courtney, Michael		65.5	0.4	RUSALCA-Fish	333702	RY12	
Dunwoody, John	M.S.	80	0.5	RUSALCA-gatew	334703	RY11	
Ershova, Elizaveta	**Ph.D.**	**1440**	**8.3**	**RUSALCA-zoop**	**333700**	RY11	Continuing Ph.D. student
Ershova, Elizaveta			**6.8**	**RUSALCA-zoop**	**333700**	RY12	
Ershova, Elizaveta			**12.0**	**RUSALCA-zoop**	**333700**	RY13	
Foster, Thomas	B.S.	38	0.2	RUSALCA-Fish	333702	RY11	
Gleason, Christine	M.S.		1.0	RUSALCA-Fish	333702	RY12	Research Tech, Fish. Ocean lab
Gray, Benjamin	B.S.	95.25	0.5	RUSALCA-Fish	333702	RY11	
Kong, Michael	**Ph.D.**		**8.5**	**RUSALCA-nuts**	**333703**	RY10	Left UAF in summer 2014
Kong, Michael		**1840**	**10.6**	**RUSALCA-nuts**	**333703**	RY11	
Kong, Michael			**8.5**	**RUSALCA-nuts**	**333703**	RY12	
Kong, Michael			4.5	RUSALCA-nuts	333703	RY13	
Larson, Brandi	B.S.	66	0.4	RUSALCA-fish	333702	RY13	
Perttu, Brian	M.S.	86	0.5	RUSALCA-fish	333702	RY11	
Peterson, Casey	B.S.	55	0.3	RUSALCA-fish	333702	RY11	
Ray, Tyler	B.S.	33	0.2	RUSALCA-fish	333702	RY11	
Ray, Tyler		18.5	0.1	RUSALCA-fish	333702	RY12	
Robinson, Matthew	B.S.	71.5	0.4	RUSALCA-fish	333702	RY11	
Ruby, Andrea	B.S.	58	0.3	RUSALCA-fish	333702	RY11	deceased
Serratos, Carlos	**M.S.**		**6.9**	**RUSALCA-benthic**	**333701**	RY13	Continuing M.S. student
Serratos, Carlos			3.6	RUSALCA-benthic	333701	RY14	
Svabik, Brian	B.A.	80	0.6	RUSALCA-gatew	334703	RY11	
Svabik, Brian		21		RUSALCA-gatew	334703	RY12	
Whitefield, Jonathan	**Ph.D.**	**1480**	**8.5**	**RUSALCA-gatew**	**334703**	RY11	Continuing Ph.D. student
Whitefield, Jonathan			**5.5**	**RUSALCA-gatew**	**334703**	RY12	

Total Ph.D.	3
Total M.S.	4
Total B.S.or B.A.	9
Total CIFAR students	16

*reporting year, 1 April to 30 March

Appendix 3. Work arising in whole or in part from RUSALCA projects funded through CIFAR (NA08OAR4320870 and NA17RJ1224) that was published or in press during the reporting period.

Authors	Publication Date	Publication Title	Published in	Type of Publication	Citation No. (doi)	Research Support Award No.	CI Lead Author	NOAA Lead Author	Other Lead Author	Peer Reviewed	Non Peer Reviewed
Nelson, R.J., R.R. Hopcroft, K.N. Kosobokova, B.P.V. Hunt and K. Young	in press	Biodiversity and biogeography of metazoan zooplankton of the Pacific Arctic Region—Sensitivities to climate change	The Pacific Arctic Sector: Status and Trends. J.M. Grebmeier, W. Maslowski and J. Zhao, Eds. Springer, New York,	Book chapter		NA08OAR4320870			X	X	
Hunt, G.L. Jr., A.L. Blanchard, P. Boveng, P. Dalpadado, K.F. Drinkwater, L. Eisner, R.R. Hopcroft, R.R., K.M. Kovacs, B.L. Norcross, P. Renaud, M. Reigstad, M. Renner, H.R. Skjoldal, A. Whitehouse and R.A. Woodgate	Jan 2013	The Barents and Chukchi Seas: Comparison of two Arctic shelf ecosystems	Journal of Marine Systems	Journal article	10.1016/j.marsys.2012.08.003	NA08OAR4320870			X	X	
Woodgate, R.A., T.J. Weingartner and R. Lindsay	Dec 2012	Observed increases in Bering Strait oceanic fluxes from the Pacific to the Arctic from 2001 to 2011 and their impacts on the Arctic Ocean water column	Geophysical Research Letters	Journal article	10.1029/2012GL054092	NA08OAR4320870			X	X	
Norcross, B.L., B.A. Holladay and C.W. Mecklenburg	May 2012	Recent and Historical Distribution and Ecology of Demersal Fishes in the Chukchi Sea Planning Area. Final Report to the Coastal Marine Institute		Technical report		NA08OAR4320870	X				X
Hondolero, D., B.A. Bluhm and K. Iken	April 2012	Caloric content of dominant benthic species from the northern Bering and Chukchi Seas: Historical comparisons and the effects of preservation	Polar Biology		10.1007/s00300-011-1107-x	NA17RJ1224	X			X	
Lee, S.H., D.A. Stockwell, H.M. Joo, Y.B. Son, C.K. Kang and T.E. Whitledge	Apr 2012	Phytoplankton production from melting ponds on Arctic sea ice	Journal of Geophysical Research	Journal article	10.1029/2011JC007717	NA17RJ1224	X			X	
Lee, S.H., H.M. Joo, M.S. Yun and T.E. Whitledge	Jan 2012	Recent phytoplankton productivity of the northern Bering Sea in the western Arctic Ocean during early summer in 2007	Polar Biology	Journal article	10.1007/s00300-011-1035-9	NA17RJ1224	X			X	
Lee, S.H., C.P. McRoy, H.M. Joo, R. Gradinger, X. Cui, M.S. Yun, K.H. Chung, S.H. Kang, C.K. Kang, E.J. Choy, S. Son, E. Carmack and T.E. Whitledge	Sept 2011	Holes in progressively thinning Arctic sea ice lead to new ice algae habitat	Oceanography	Journal article	10.5670/oceanog.2011.81	NA17RJ1224	X			X	
Piepenburg, D., P. Archambault, W.G. Ambrose Jr., A.L. Blanchard, B.A. Bluhm, M.L. Carroll, K.E. Conlan, M. Cusson, H.M. Feder, J.M. Grebmeier, S.C. Jewett, M. Levesque, V.V. Petryashev, M.K. Sejr, B.I. Sirenko and M. Wlodarska-Kowalczuk	March 2011	Towards a pan-Arctic inventory of the species diversity of the macro- and megabenthic fauna of the Arctic shelf seas	Marine Biodiversity	Journal article	10.1007/s12526-010-0059-7	NA17RJ1224			X	X	

Wei, C-L., G.T. Rowe, E. Escobar-Briones, A. Boetius, T. Soltwedel, M.J. Caley, Y. Soliman, F. Huettmann, F. Qu, Z. Yu, C.R. Pitcher, R.L. Haedrich, M.K. Wicksten, M.A. Rex, J.G. Baguley, J. Sharma, R. Danovaro, I.R. MacDonald, C.C. Nunnally, J.W. Deming, P. Montagna, M. Levesque, J.M. Weslawski, M. Wlodarska-Kowalczuk, B.S. Ingole, B.J. Bett, D.S.M. Billett, A. Yool, B.A. Bluhm, K. Iken and B.E. Narayanaswamy	Dec 2010	Global patterns and predictions of seafloor biomass using random forests	PLoS ONE	Journal article	10.1371/journal.pone.0015323	NA17RJ1224			X	X	
Lee, S.H., M. Jin and T.E. Whitledge	Oct 2010	Comparison of bottom sea-ice algal characteristics from coastal and offshore regions in the Arctic Ocean	Polar Biology	Journal article	10.1007/s00300-010-0820-1	NA17RJ1224	X			X	
Lee, S.H., D. Stockwell and T.E. Whitledge	Aug 2010	Uptake rates of dissolved inorganic carbon and nitrogen by under-ice phytoplankton in the Canada Basin in summer 2005	Polar Biology	Journal article	10.1007/s00300-010-0781-4	NA17RJ1224	X			X	
Bucklin, A., R.R. Hopcroft, K.N. Kosobokova, L.M. Nigro, B.D. Ortman, R.M. Jennings and C.J. Sweetman	Jan 2010	DNA barcoding of Arctic Ocean holozooplankton for species identification and recognition	Deep Sea Research II	Journal article	10.1016/j.dsr2.2009.08.005	NA17RJ1224			X	X	
Hopcroft, R.R. and K.N. Kosobokova	Jan 2010	Distribution and egg production of *Pseudocalanus* species in the Chukchi Sea	Deep Sea Research II	Journal article	10.1016/j.dsr2.2009.08.004	NA17RJ1224	X			X	
Hopcroft, R.R., K.N. Kosobokova and A. Pinchuk	Jan 2010	Zooplankton community patterns in the Chukchi Sea during summer 2004	Deep Sea Research II	Journal article	10.1016/j.dsr2.2009.08.003	NA17RJ1224	X			X	
Norcross, B.L., B.A. Holladay, M.S. Busby and K.L. Mier	Jan 2010	Demersal and larval fish assemblages in the Chukchi Sea	Deep Sea Research II	Journal article	10.1016/j.dsr2.2009.08.006	NA17RJ1224	X			X	
Iken, K., B. Bluhm and K. Dunton	Jan 2010	Benthic food-web structure under differing water mass properties in the southern Chukchi Sea	Deep Sea Research II	Journal article	10.1016/j.dsr2.2009.08.007	NA17RJ1224	X			X	
Pickart, R.S., L.J. Pratt, D.J. Torres, T.E. Whitledge, A.Y. Proshutinsky, K. Aagaard, T.A. Agnew, G.W.K. Moore and H.J. Dail	Jan 2010	Evolution and dynamics of the flow through Herald Canyon in the western Chukchi Sea	Deep Sea Research II	Journal article	10.1016/j.dsr2.2009.08.002	NA17RJ1224			X	X	
Woodgate, R. A., T. Weingartner and R. Lindsay	Jan 2010	The 2007 Bering Strait oceanic heat flux and possible relationships to anomalous Arctic Sea Ice Retreat.	Geophysical Research Letters	Journal article	10.1029/2009GL041621	NA17RJ1224			X	X	
Sirenko, B.I., B.A. Bluhm, K. Iken, K. Crane and V. Gladish	late 2009	Some results of investigation of composition and trophic groups of zoobenthos in the Chukchi Sea	Explorations of the Fauna of the Seas, 64(72):200–212.	Journal article		NA17RJ1224			X	X	
Bluhm, B.A., K. Iken, S. Mincks Hardy, B.I. Sirenko and B.A. Holladay	Dec 2009	Community structure of epibenthic megafauna in the Chukchi Sea	Aquatic Biology	Journal article	10.3354/ab00198	NA17RJ1224	X			X	

Additional peer-reviewed publications that utilized RUSALCA data, shiptime, and/or scientific collaboration

Torres-Valdes, S., T. Tsubouchi, S. Bacon, A.C. Naveira-Garabato, R. Sanders, F.A. McLaughlin, B. Petrie, G. Kattner, K. Azetsu-Scott and T.E. Whitledge	Apr 2013	Export of nutrients from the Arctic Ocean	Journal of Geophysical Research–Oceans	Journal article	10.1012/jgrc.20063	NA17RJ1224			X	X	
Walsh, J.J., D.A. Dieterle, F.R. Chen, J.M. Lenes, W. Maslowski, J.J. Cassano, T.E. Whitledge, D. Stockwell, M.V. Flint, I.N. Sukhanova and J. Cristensen	Nov 2011	Trophic cascades and future harmful algal blooms within ice-free Arctic Seas north of Bering Strait: A simulation analysis	Progress in Oceanography	Journal article	10.1016/j.pocean.2011.02.001	NA17RJ1224			X	X	
Purcell, J.E., R.R. Hopcroft, K.N. Kosobokova and T.E. Whitledge	Jan 2010	Distribution, abundance, and predation effects of epipelagic ctenophores and jellyfish in the western Arctic Ocean	Deep Sea Research II	Journal article	10.1016/j.dsr2.2009.08.011	NA17RJ1224			X	X	