

# Coastal Marine Institute

**University of Alaska**

## **Annual Report No. 17**

Calendar Year 2010  
BOEMRE 2011-029

Submitted by  
Michael Castellini  
Director  
University of Alaska Coastal Marine Institute

to

U.S. Department of the Interior  
Bureau of Ocean Energy Management,  
Regulation and Enforcement  
Alaska OCS Region  
Anchorage, Alaska

May 2011

**Bureau of Ocean Energy Management, Regulation and Enforcement  
Department of the Interior**

and the

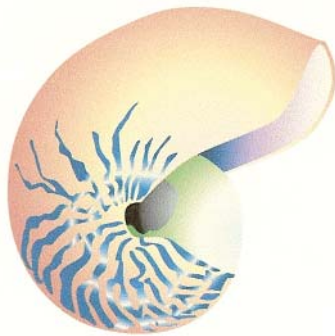
**School of Fisheries & Ocean Sciences  
University of Alaska Fairbanks**

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## Introduction

The University of Alaska Coastal Marine Institute (CMI) was created by a cooperative agreement between the University of Alaska and the original Minerals Management Service (now Bureau of Ocean Energy Management, Regulation and Enforcement (BOEMRE) in June 1993, with the first full funding cycle beginning late in (federal) fiscal year 1994. CMI is pleased to present this 2010 Annual Report, our 17th annual report. We are currently working under BOEMRE Cooperative Agreement M03PC00003.

BOEMRE administers the outer continental shelf (OCS) natural gas, oil, and marine minerals program overseeing the safe and environmentally sound leasing, exploration, and production of these resources within our nation's offshore areas. The Environmental Studies Program (ESP) was formally directed in 1978, under Section 20 of the OCS Lands Act Amendments, to provide information in support of the decisions involved in the planning, leasing, and management of exploration, development, and production activities. The research agenda is driven by the identification of specific issues, concerns, or data gaps by federal decision makers and the state and local governments that participate in the process. ESP research focuses on the following broad issues associated with development of OCS gas, oil, and minerals:

- What are the fates and effects of potential OCS-related pollutants (e.g., oil, noise, drilling muds, and cuttings, products of fuel combustion) in the marine and coastal environment and the atmosphere?
- What biological resources (e.g., fish populations) exist and which resources are at risk? What is the nature and extent of the risk? What measures must be taken to allow extraction to take place?
- How do OCS activities affect people in terms of jobs and the economy? What are the direct and indirect effects on local culture? What are the psychological effects of the proposed OCS activities?

Because BOEMRE and individual states have distinct but complementary roles in the decision-making process, reliable scientific information is needed by BOEMRE, the state, and localities potentially affected by OCS operations. In light of this, BOEMRE has developed a locally managed CMI program. CMI is administered by the University of Alaska Fairbanks School of Fisheries and Ocean Sciences. Alaska was selected as the location for this CMI because it contains some of the major potential offshore oil and gas producing areas in the United States. The University of Alaska Fairbanks is uniquely suited to participate by virtue of its flagship status within the state and its nationally recognized marine and coastal expertise relevant to the broad range of OCS program information needs. In addition, BOEMRE and the University of Alaska have worked cooperatively on ESP studies for many years. Research projects funded by CMI are required to have at least one active University of Alaska investigator. Cooperative research between the University of Alaska and state agency scientists is encouraged.

Framework Issues were developed during the formation of CMI to identify and bracket the concerns to be addressed:

- Scientific studies for better understanding marine, coastal, or human environments affected or potentially affected by offshore oil & gas or other mineral exploration and extraction on the outer continental shelf;
- Modeling studies of environmental, social, economic, or cultural processes related to OCS oil & gas activities in order to improve scientific predictive capabilities;
- Experimental studies for better understanding of environmental processes or the causes and effects of OCS activities;
- Projects which design or establish mechanisms or protocols for sharing of data or scientific information regarding marine or coastal resources or human activities to support prudent management of oil & gas and marine minerals resources; and
- Synthesis studies of scientific environmental or socioeconomic information relevant to the OCS oil & gas program. Projects funded through CMI are directed toward providing information which can be used by BOEMRE and the state for management decisions specifically relevant to BOEMRE mission responsibilities.

Projects must be pertinent to either the OCS oil and gas program or the marine minerals mining program. They should provide useful information for program management or for the scientific understanding of potential environmental effects of resource development activities in arctic and subarctic environments.

Initial guidelines given to prospective researchers identified Cook Inlet and Shelikof Strait, as well as the Beaufort and Chukchi seas, as areas of chief concern to BOEMRE and the state. Primary emphasis has subsequently shifted to the Beaufort Sea, and to the Chukchi Sea as it relates to the Beaufort Sea.

The proposal process is initiated each summer with a request for proposals to addressing one or more of the Framework Issues. This request is publicized and sent to researchers at the University of Alaska, to various state agencies, and to relevant profit and non-profit corporations. The proposals are reviewed both externally and by BOEMRE internally. The CMI technical steering committee then decides which proposals should be recommended to BOEMRE for funding.

Successful investigators are strongly encouraged to publish their results in peer-reviewed journals as well as to present them at national meetings. In addition, investigators report their findings at the CMI's annual research review at UAF. Some investigators present information directly to the public and BOEMRE staff in seminars.

Alaskans benefit from the examination and increased understanding of those processes unique to Alaskan OCS and coastal waters because this enhanced understanding can be applied to problems other than oil, gas, and mineral extraction, such as subsistence fisheries and northern shipping.

Many of the CMI-funded projects address some combination of issues related to fisheries, biomonitoring, physical oceanography, and the fates of oil. The ultimate intent of CMI-related research is to identify the ways in which OCS-related activities may affect our environment, and potential economic and social impacts as well.

**On-Going Studies:**



# Recovery in a High Arctic Kelp Community Includes Appendix on Boulder Patch Fish Assemblages

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**Project Start – End Dates: 6/29/2009 – 12/30/2012**  
**Cooperative Agreement Number: M08AC12645**

## **Abstract**

The overarching goal of this project is to acquire a better understanding of how sessile communities recover after disturbances in the Boulder Patch, a high arctic kelp community. In general, high arctic kelp communities in Prudhoe Bay are considered sensitive habitats and have the potential of being impacted by oil and gas activities. One such kelp community located adjacent to BP leased lands is the Boulder Patch. It has been shown that if sessile organisms such as macroalgae and sponges, are killed or removed in the Boulder Patch, the recovery of this community is very slow. What is unknown is exactly how slow recruitment is, the reasons for this slow recruitment, and how communities might naturally recover from disturbances. Overall, this project will determine the timing of natural recruitment, the impact of grazers and sedimentation on recruitment, and the rate of vegetative re-growth. This year, we focused on the vegetative re-growth of sessile sponges and encrusting coralline algae, two of the dominant space occupiers. This was done by monitoring re-growth into clearings that were established in 2007. Thus far, we have found that vegetative re-growth can be fast at our primary site (DS11), especially when compared to propagule recruitment. After two years at the primary study site, sponges averaged  $69.6 \pm 15.5$  % regrowth and coralline regrowth averaged  $10.0 \pm 10.3$  %. The large variation is due to one sponge and two corallines that are dying at this site. Death in these individuals is causing them to have a negative growth rate. At the satellite site, which has much higher sedimentation, corallines were not re-growing and were in fact, also dying. These corallines had a  $54.2 \pm 32.7$  % loss of space on the substrate after two years. Overall, this study is demonstrating that recovery from disturbances can be very slow on hard substrates in the Boulder Patch, especially if entire organisms are removed or killed. However, if some part of either the sponge or coralline remains on the substrate after the disturbance, recovery may be much quicker. It appears that sedimentation may be playing a role in re-growth.

## **Introduction**

Alaska's Beaufort Sea shelf is typically characterized by silty sands and mud and as having an absence of macroalgal beds and associated organisms (Barnes and Reimnitz 1974). In 1971, a diverse kelp and invertebrate community was discovered near Prudhoe Bay in Stefansson Sound, Alaska. Since its discovery, the Boulder Patch has been subject to much biological and geological research (Dunton et al. 1982; Dunton 1985; Dunton and Schell 1987; Dunton and Jodwalis 1988; Dunton 1990; Martin and Gallaway 1994; MMS 1996; 1998; Dunton and Schonberg 2000; Debenham 2005; Konar and Iken 2005; Aumack et al. 2007; Konar 2007). The

Boulder Patch contains large numbers of cobbles and boulders that provide a substrate for attachment for a diverse assortment of invertebrates and several species of red and brown algae. The predominant alga is the brown, *Laminaria solidungula*, which constitutes 90% of the brown algal biomass (Dunton et al. 1982). This alga is an important food source to many benthic and epibenthic organisms (Dunton and Schell 1987; Debenham 2005). Approximately 148 animal taxa and 10 algal species cover nearly all exposed substrate at densities approaching 18,441 individuals/m<sup>2</sup> with an average biomass of 283 g/m<sup>2</sup> (Dunton and Schonberg 2000). In the Boulder Patch, sponge cover can be variable, including a complete absence of sponges in some areas with higher sedimentation. Differences in infaunal abundance and biomass between the Boulder Patch and peripheral sediment areas demonstrate the importance of this unique habitat (Dunton and Schonberg 2000).

In temperate marine systems, boulder fields are very dynamic because of physical disturbance (Sousa 1979; 1980; vanTamelon 1987). When a boulder is overturned, the sessile community can be killed in whole or part by a combination of grazing, anoxia, low light levels, or mechanical damage caused by crushing or abrasion (Sousa 1980). Studies in temperate systems have shown that algal communities can recover to previous densities within one year of denuding (Foster 1975; Bertness et al. 2004; Milazzo et al. 2004). Many studies on coralline algal recruitment have shown that although their growth is remarkably slow, they will settle and grow to a visible size in a few months (Adey and Vasser 1975; Matsuda 1989; Konar and Foster 1992).

In contrast to temperate systems, recruitment in high Arctic systems appears to be much slower (Dunton et al. 1982). A recolonization experiment in the Boulder Patch demonstrated that recovery of denuded areas is slow with 50% of the substrate still being bare three years after an initial disturbance (Dunton et al. 1982). Another recolonization experiment in the Boulder Patch, which began in 2002, also demonstrated and reinforced the idea that this community is very slow to recover from disturbances (Konar 2007). In this latter study, less than 5% of the substrate was recolonized four years after clearing. While there was variation in the recovery of these two studies, this slow recruitment in high arctic waters is considered typical (Barnes and Kuklinski 2005). The difference in the recruitment between the two studies may be due to how the initial clearings were made. In the latter study, boulders were brought to the surface, cleared, and left in the sun for one week to kill any residual seed bank. The removal of all propagules in this way would obviously make recovery harder. Another attribute that needs to be considered when discussing the slow recovery specifically in the Boulder Patch is that species in Alaska and other higher latitude areas may be more sensitive to oil contamination/spills than their temperate counterparts (Rice et al. 1976). Also, since there are generally fewer species in the arctic, the food chains are shorter. When a species is lost due to an oil spill or similar, the very limited and smaller pool of available replacement species has been suggested to have relatively large repercussions on community recovery (Rice et al. 1980). The reason why recruitment in the absence of an oil spill is so slow in the Boulder Patch remains unknown.

## **Objectives/Hypotheses**

To further our understanding of Boulder Patch recruitment and recovery dynamics the following objectives and hypotheses are being examined as part of this study:

*Objective 1: Determine the timing of natural recruitment on to hard substrates.*

H1) Recruitment is slow and episodic in the Boulder Patch.

*Objective 2: Determine the effect that grazers have on the timing of recruitment.*

H2) Grazers slow the initial recruitment of sessile organisms.

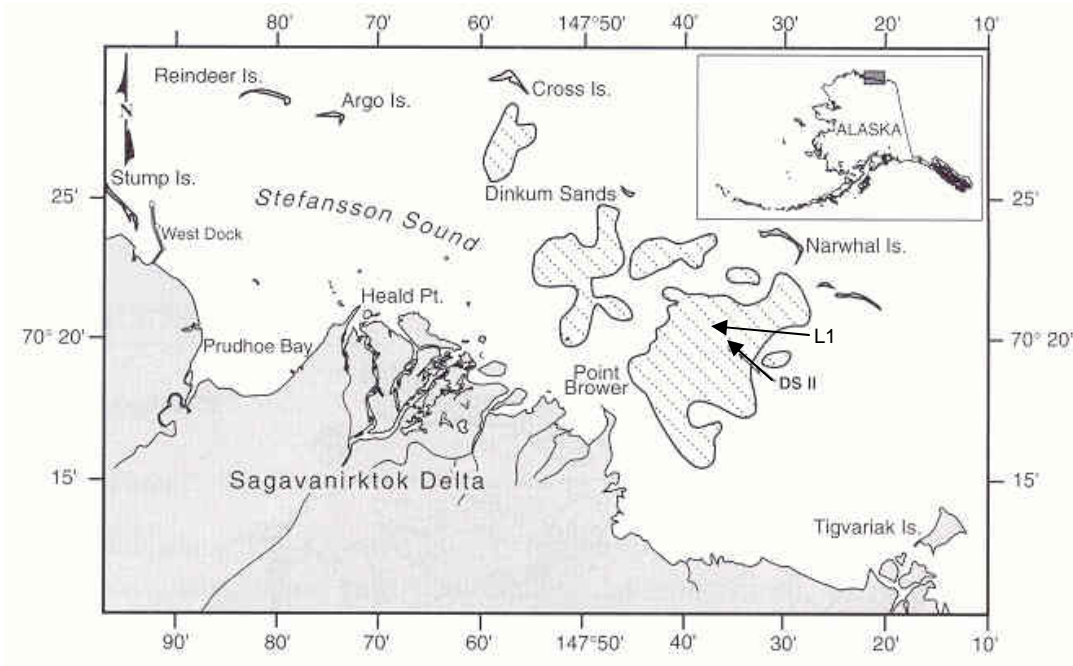
*Objective 3: What effect does sedimentation have to the timing of recruitment?*  
H3) Sedimentation slows initial recruitment of sessile organisms.

*Objective 4: What is the rate of vegetative re-growth of various sessile organism groups?*  
H4) Community recovery via vegetative re-growth is the primary means of recovery from disturbances while recovery via recruitment events plays only a minor role.

This annual report will focus on Objective 4.

## Study Area

This study was largely conducted at site DS-11 (N 70° 19.336, W 147° 34.903), which is within the Boulder Patch in Stefansson Sound, Beaufort Sea (Figure 1). A satellite site also was established at L1 (N 70° 17.328, W 147° 36.621) to examine spatial differences in vegetative re-growth at different boulder patches within the overall Boulder Patch area. Both study sites are in 6-7 m water depth and contain numerous cobbles and boulders that provide substrate for several invertebrate and macroalgal species. The study sites were similar in that they both had foliose macroalgae (*Laminaria* and *Alaria*) and encrusting coralline algae along with a variety of invertebrates. One obvious difference between the two sites is that sponges were conspicuous at DS-11, while they were largely absent from L1. L1 also had overall less rock cover and more sedimentation.

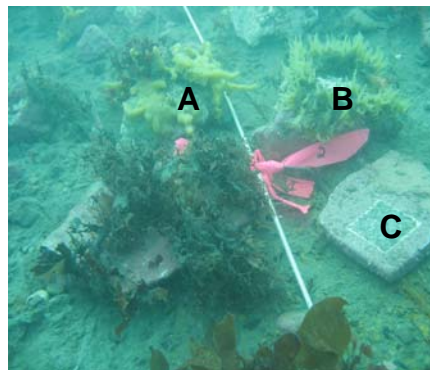


**Figure 1. Chart of Boulder Patch showing approximate locations of DS-11 and L1 within Stefansson Sound. Hatched polygons are areas with high boulder/cobble density. From Dunton and Schonberg 2000.**

## Methods

*Objective 4: What is the rate of vegetative re-growth of various sessile organism groups?*

For this objective, various rocks had 4 cm x 4 cm clearings made on them at three different areas within DS-11 and L-1 in 2007 (Figure 2). At DS-11, six boulders had clearings centered in an encrusting coralline patch and twelve were within encrusting sponge patches. At L1, six boulders had patches of coralline algae cleared. Sponges were not found at L-1 so clearings could not be done there. Each organism patch extended at least 2 cm beyond the cleared area to ensure enough material for re-growth. These cleared areas have been monitored for vegetative re-growth using digital photography. Re-growth of the organisms on the photographs has been compared using SigmaScan. Each year, the percentage of re-growth has been determined.



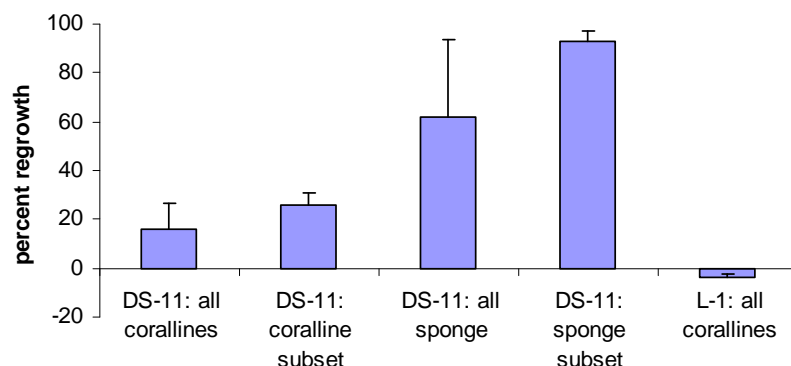
**Figure 2. One set of cleared rocks at DS-11. A and B are sponge clearings. C is within an encrusting coralline.**

## Preliminary Results

*Objective 4: What is the rate of vegetative re-growth of various sessile organism groups?*

In 2010, six cleared coralline rocks and seven cleared sponge rocks were relocated and photographed at DS-11. In addition to these, three cleared coralline rocks were found at L-1. Re-growth since the initial clearing was seen on most rocks with the most re-growth occurring on the sponge cleared rocks (Figure 3). At DS-11, two of the corallines and one of the sponges appeared to be dying so there was negative growth on these boulders. The reason for this mortality is unknown. When these rocks are excluded from the analyses, re-growth since the initial clearing on the corallines and sponges were approximately 10% and 70% respectively (Figure 3). It was expected that more re-growth would occur on the sponge cleared rocks as these typically grow faster, particularly when compared to encrusting coralline algae. Although coralline algae are known to be extremely slow growers (Konar and Foster 1992), substantial growth was seen over the three year period. Next year, all clearings will be re-photographed and additional growth will be calculated.

In addition to re-sampling the clearings, next year we will also try to relocate and sample as many of the past experiments as possible. These experiments are looking at general recruitment and the effects of grazers and sedimentation. We also will resurvey the status of the general community at both the DS-11 and L1 sites.



**Figure 3. Mean percent re-growth ( $\pm 1$  s.e.) of all DS-11 corallines (n=6), a subset of DS-11 corallines after the two dying corallines were excluded (n=4), DS-11 sponges (n=7), a subset of DS-11 sponges after the one dying sponge was excluded (n=5), and corallines from L-1 (n=3).**

## Acknowledgements

Logistical support is being provided by the Dunton Brothers and the Bureau of Ocean Energy Management, Regulation and Enforcement (particularly Kate Wedemeyer, Cathy Coon, and Captain Gary Lawley). Access to the Boulder Patch made available by BP. Ken Dunton, Nathan Stewart, Terry Efird, and Kate Wedemeyer provided essential field assistance. This project is being funded by the Coastal Marine Institute.

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## **Appendix 1: Boulder Patch Fish Assemblages**

### **Introduction**

The discovery of petroleum on Alaska's North Slope in 1969 has triggered research on marine communities inhabiting the Beaufort Sea coastal waters in response to concerns about the potential impacts of oil development on indigenous species and their habitats (Jarvela and Thornsteinson 1998). Most of this work has taken place in the vicinity of Prudhoe Bay, the present center of production activities, and in adjacent waters in the coastal Arctic. Areas in Stefansson Sound has been central to much of this survey effort due to the occurrence of a unique nearshore habitat dominated by boulders, appropriately named the Boulder Patch (Figure 1 in main text). The Boulder Patch is a shallow (less than 10 m water depth) nearshore habitat, covering approximately 20 km<sup>2</sup> of seabed, and is characterized by cobbles and small boulders in an area otherwise dominated fine-grained sediments, silty sands, and/or mud. The boulders in the Boulder Patch provide a substrate for attachment for algae and sessile invertebrates and refuge habitat for fish.

Recent studies in this habitat have focused on macroalgal and invertebrate communities (starting with Dunton et al. 1982), however the epipelagic fish community has yet to be fully described. Epilithic sampling of rocks in the Boulder Patch has shown that fish do inhabit this area (*Liparis* sp., *Liparis herschelinus*, *Myoxocephalus scorpioides* and Stichaeidae; Dunton and Schonberg 2000). Studies conducted in nearshore waters elsewhere in the Prudhoe Bay region (Tarbox and Moulton 1980; Craig et al. 1982; Craig 1984; Moulton and Tarbox 1987; Gallaway et al. 1991) also provide reference for species assemblage structure and habitat associations pertinent to this study and suggest that the fish community associated with the boulder patch is likely comprised of adult and larval fishes that commonly associate with rocky substrates and neritic riverine-influenced systems. The primary goal of this pilot study was to quantify fish diversity and abundance in the Boulder Patch by examining (1) fish community composition; (2) species' distributions, abundances, and visual estimation of individual fish length; and (3) species' relationships to habitat attributes such as benthic grain size and macroalgal distribution and abundance.

### **Study Area**

Epipelagic fishes were surveyed in the Boulder Patch in Stefansson Sound (N 70° 19.336, W 147° 34.903), located 20 km northeast of Prudhoe Bay, Alaska, in the Beaufort Sea. Sites that were surveyed within the Boulder Patch were DS11, L1, and an area outside these patches by L1 (Figure 1 in previous section). As each transect had varying amounts of boulders, analyses will be completed by physical attributes and not by site.

### **Methods**

This pilot study conducted two survey methods in three areas within the Boulder Patch (DS11, L1, and an area adjacent to L1). At DS11, three transects were completed at each of two sites (totaling 6 transects). At L1, three transects were conducted at each of two sites (totaling 6 transects). Three transects were also conducted an area adjacent to L1. The reason why different areas were chosen was to try to get a range of boulder densities and algal cover.

The first method utilized diver visual surveys conducted along randomly placed 50 m x 2 m x 2 m transects. Fish observed along these transects were identified to species and their length estimated



to the nearest centimeter. Diver surveys consisted of an initial search that targeted mobile species within 2 m (vertical distance) of the substrate and species that were shown to move quickly through the survey area. A second search along the same transects targeted cryptic species associated with the substrate and perhaps hidden under the macroalgae. In the adjacent sandy areas, only the first search was done as there is no place for fish to hide in this habitat.

Along each transect, rugosity and kelp stipe counts were calculated. Rugosity is a measure of substrate topography and is a ratio of the topographical distance compared to a straight line distance. Rugosity was measured using a 1 m polyvinyl chloride (PVC) bar with a length of small mesh (5 mm diameter) chain attached to one end. At six points along each transect, the PVC bar was laid perpendicular to the transect, and the chain was placed in the same direction but allowed to drape and follow the substrate topography. At the end of the PVC bar, the chain was marked, straightened, and measured to provide the rugosity ratio. To determine the total number of kelp stipes along each transect, six 0.25m<sup>2</sup> quadrats were examined per transect. All understory kelps in each quadrat were counted.

The second method used consisted of observation stations baited with herring. These stations were under video surveillance without divers being present for a 30 minute timed survey period. These surveys were designed to better estimate biodiversity and abundance of small and/or cryptic fish. Two stations were videoed, one in DS11 and one in L1. The videos were completed to determine if this might be a feasible way to examine fish diversity between sites.

## Results

All fish seen in the surveys conducted in this study were *Liparis* spp. (snailfish). Within DS-11, only one individual was found in the six transects that were conducted for a mean fish density of 0.0008 per m<sup>3</sup>. At L1, three individuals were counted along the six transects for a mean fish density of 0.0025 per m<sup>3</sup>. In the area outside of DS-11, four fish were found along the three transects that were conducted for a mean fish density for 0.0067 per m<sup>3</sup>.

In Alaska, rugosity and kelp cover are known to influence fish assemblages (Hamilton and Konar 2007; Markis 2007) so correlations between these two factors were examined for the Boulder Patch fish assemblage. Interestingly, neither rugosity nor kelp cover seemed to influence the fish assemblage (Figures 1 and 2).

Video surveillance was not successful for examining fish diversity between sites. Although the cameras soaked for 30 minutes and were baited, no fish were observed on the video. The camera was working however as it did get images of various invertebrates moving through the stations.

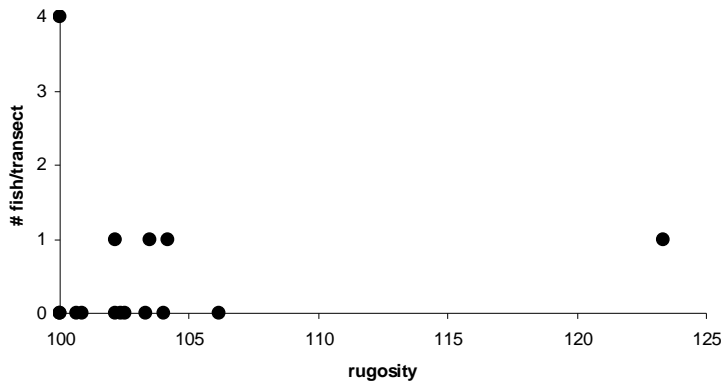


Figure 1. Total number of fish per transect related to average rugosity per transect.

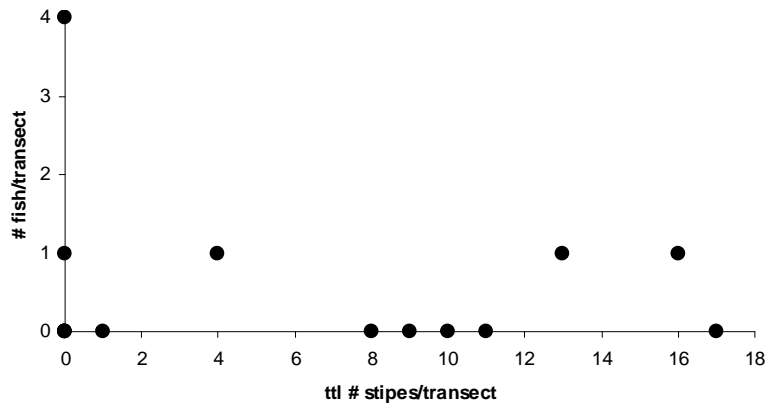


Figure 2. Total number of fish per transect related to total number of stipes per transect.

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# Biogeochemical Assessment of the North Aleutian Basin Ecosystem: Current Status and Vulnerability to Climate Change

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**Project Start – End Dates: 06/01/2008 – 12/31/2012**  
**Cooperative Agreement Number: M08AX12760**

## Introduction

The overall goal of this project is to gain a better understanding of the carbon biogeochemistry of the Bering and Chukchi Sea ecosystem and the controls that regulate the cycling and transformation of carbon and nitrogen in the marine environment. Broadly, the project has the following objectives; (i) quantify upper ocean net ecosystem production, (ii) determine the fate of net community production, (iii) assess the impact of climate variability (i.e. El Niño, Pacific Decadal Oscillation, Arctic Oscillation) on carbon biogeochemistry, (iv) determine the extent of ocean acidification in the Bering and Chukchi Sea and develop long term projections for changes in the pH.

## Project Status

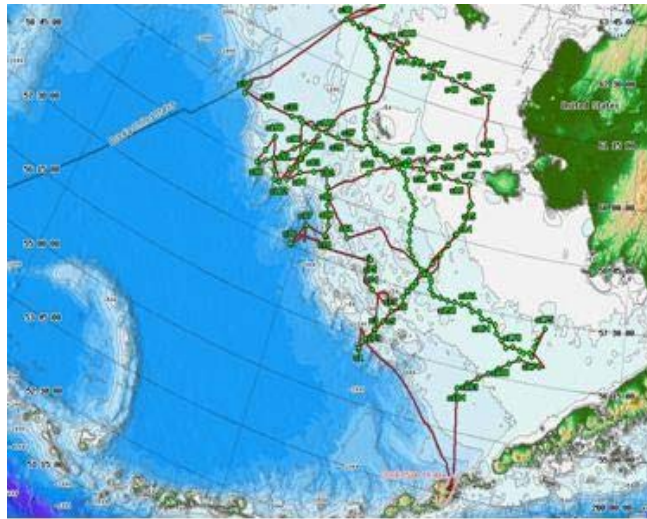
Work continued on the project throughout 2010. The year began with the continued analysis of samples collected in the Bering Sea in spring, summer and fall of 2009 (Figure 1). The analysis of approximately 1,000 samples for dissolved inorganic carbon (DIC), total alkalinity (TA), and total organic carbon (TOC) was completed in February.

As expected, both DIC and TA were tightly correlated with salinity in spring prior to ice melt. Data from summer showed that DIC concentrations had been drawn down considerably in the surface waters as a result of primary production. Using DIC deficits between spring and summer we were able to determine rates of net community production across the Bering Sea shelf. We found that rates of production were higher in the northern shelf. There was also a strong remineralization signature in the bottom waters of the northern shelf that were evident in high DIC concentrations near the bottom. The results are discussed in detail in a recent paper (Mathis et al., 2010) and several that are pending (Mathis et al., in press; Cross and Mathis, in review).

The increases in DIC at depth caused an increase in the partial pressure of carbon dioxide ( $p\text{CO}_2$ ) (Bates et al., in press) in the bottom waters in certain locations and suppressed the saturation states of carbonate minerals (Mathis et al., in press). In particular, aragonite was undersaturated over the northern most part of the shelf. These waters could be potentially corrosive to benthic calcifiers in the region including the commercially important crab fishery. Also alarming was the presence of waters undersaturated with respect to aragonite in the inner most stations that were occupied in both spring and summer. The source of these low pH, high  $p\text{CO}_2$  waters is likely the Yukon and Kuskokwim Rivers, which also contain these biogeochemical signatures.

In 2010, we had the opportunity to participate in two more planned cruises in the Bering Sea as well as three cruises in the Chukchi Sea (part of the expanded projected objectives). In all, we collected over 1,800 samples for DIC and TA. All of these samples were returned to the lab and analysis began in December and is about 20% complete.

Jessica Cross, the PhD student involved in the project continued to make excellent progress and is responsible for much of the project's success. In all, she spent approximately 80 days at sea in 2010 and is now done with the fieldwork component of her project. She wrote a first author publication (Cross and Mathis, in review) and presented a summary of the research at the AMSS in January 2011. Now that the fieldwork is over, we are moving into the synthesis phase of the project. A supplemental requested was submitted and approved by CMI for funds to support a post doctoral investigator who will help with the tremendous dataset that has been collected during the three years of fieldwork. Ideally, this person will be in place by summer of 2011.



**Figure 1: Cruise track and station locations for spring and summer 2008**

## **Study Products**

Mathis, J.T., Cross, J.N., Bates, N.R., Lomas, M.L., Moran, S.B., Mordy, C.W., Stabeno, P., (2010). Seasonal Distribution of Dissolved Inorganic Carbon and Net Community Production on the Bering Sea Shelf (*Biogeosciences*, 7, 1769–1787, doi:10.5194/bg-7-1769-2010).

Mathis, J.T., Cross, J.N., Bates, N.R., Coupling Primary Production and Terrestrial Runoff to Ocean Acidification and Carbonate Mineral Suppression in the Eastern Bering Sea *Journal of Geophysical Research-Oceans* (In Press – *Journal of Geophysical Research*).

Bates, N.R., Mathis, J.T., Jefferies, M.A., Air-Sea CO<sub>2</sub> fluxes on the Bering Sea Shelf. (*Biogeosciences* – in press).

Cross, J. N., and Mathis, J.T., Hydrographic Controls on Net Community Production and Total Organic Carbon Distributions in the Eastern Bering Sea. (Submitted - *Deep Sea Research II*).

# Mapping and Characterization of Recurring Polynyas and Landfast Ice in the Chukchi Sea

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**Cooperative Agreement Number: M09AC15191**

## **Abstract**

This project is the continuation and extension of an earlier project with the same title. Our aim is to apply methodologies developed during the previous project to map and characterize leads and landfast sea ice in an expanded study area including both the Beaufort and Chukchi Seas. Significant progress was made during 2010 toward analysis of lead patterns and landfast sea ice extent throughout the expanded study area. We have completed a time-consuming manual inspection of daily advanced very high resolution radiometer (AVHRR) data that has identified a number of new recurring lead patterns and also cataloged cloud-free regions, which will facilitate the next step, which involves quantitative analysis of leads.

We have also successfully adapted most of the software tools for analysis of landfast sea ice data that we developed in the previous project for implementation in the expanded study area. However, some unanticipated issues with acquisition and processing of synthetic aperture radar (SAR) imagery have meant that we have not generated as much seaward landfast ice edge (SLIE) data as we had expected. We are confident that these issues will be resolved in the coming year. In this report, we present preliminary data for the Chukchi Sea study region and compare it with results for the Beaufort Sea from the previous project. We have also successfully applied a new method for locating SLIEs that uses interferometric SAR techniques. Results from this technique and comparison with the standard methodology are presented in a manuscript that will be submitted for publication in a peer-reviewed journal early in 2011.

## **Introduction**

This project is the continuation and extension of a earlier project with the same title. The first project (AK-03-06, MMS-71707, active from 2004-2006) was confined to the Beaufort and eastern Chukchi Sea and the time period 1993-2004. The current project (CMI/MMS09HQPA0004T, active 2009-present) extends the study area to cover the entire Chukchi Sea and covers the years 1993-2008 and when complete, will supersede the first project.

The aim of this continuing study is to map and document the spatial and temporal distribution of recurring lead systems, coastal polynyas and landfast ice in the Beaufort and Chukchi Seas. The study region encompasses the entire northern coast of Alaska and parts of the Russian and Canadian coasts. This includes oil and gas leases sold in 2008 for which sea-ice information is lacking. The region and its sea ice cover are also of importance to protected marine mammals and birds. Dramatic reductions in Arctic summer sea ice extent since 2005 lend

urgency to the need for improved knowledge and understanding of the physical sea ice environment in this region of the Arctic.

The methods we use for mapping and characterizing leads and landfast sea ice were developed during the first iteration of this project, which covered a smaller study region for the period 1993-2004. The full description, final report and summary data for the first project are available at <http://mms.gina.alaska.edu>.

To determine the annual cycle of landfast sea ice extent, we examine co-located triplets of mosaicked Radarsat Synthetic Aperture Radar (SAR) imagery that span a period of approximately 20 days. We define landfast sea ice as that which is adjacent to the coast and remains stationary for the period spanned by the triplet. The SAR data allow us to delineate the seaward landfast ice edge (SLIE) at 100m spatial resolution approximately 30 times per season (approximately every 10 days). From these results, we can determine minimum, mean and maximum landfast ice extent on a monthly basis and calculate average dates of formation, stabilization and break up along different sections of the coast.

For analyzing lead patterns, we rely on Advanced Very High Resolution Radiometer (AVHRR) data. Our approach combines a qualitative analysis of characteristic patterns with quantification of the size, orientation, location and recurrence of individual leads. The qualitative analysis involves manual examination of daily images, which also allows the identification of cloud-free scenes suitable for digital image processing.

When the current project is complete, we will have analyzed mapped and characterized recurring leads within the study region for the period 1994-2008. The availability of Radarsat SAR data restricts the landfast ice analysis to the period 1996-2007, but we are also developing an interferometric SAR (InSAR) technique to identify landfast sea ice using the Phased Array L-band SAR (PALSAR) radar sensor on the Advanced Land Observation Satellite (ALOS).

## **Objectives**

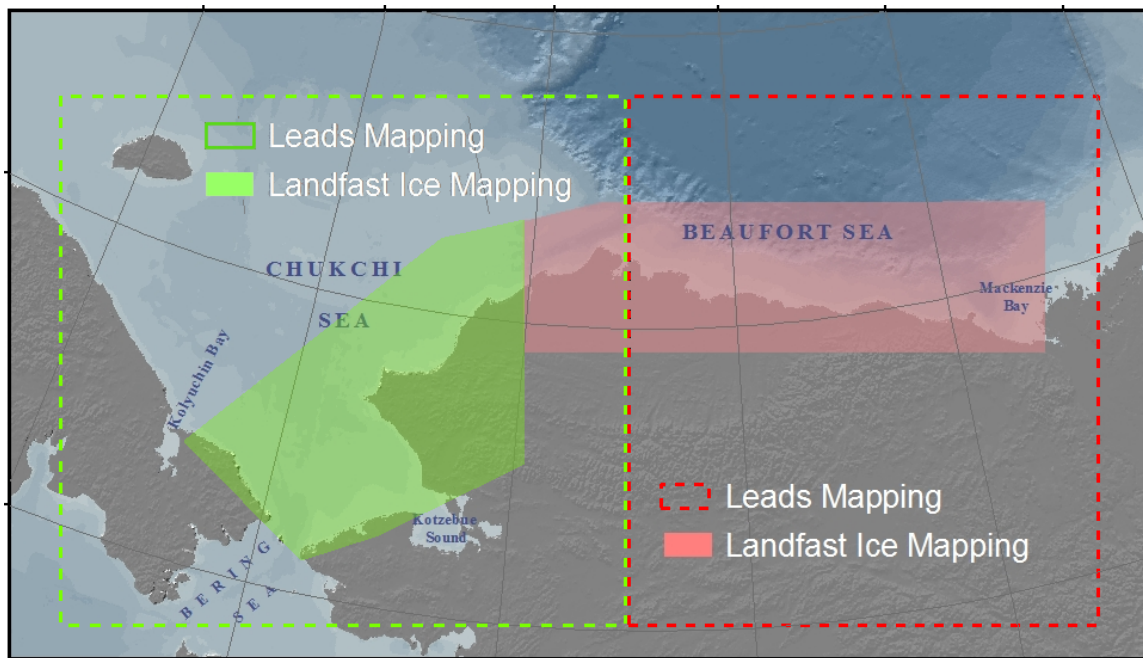
The objective of this project is to update the results of first study from its initial time span (1993-94 to 2003-2004 ice years) to the 2007-2008 ice year, and to extend the study to include the Chukchi Sea coasts of Alaska and the Chukchi Peninsula of eastern Siberia over the entire time period from 1993-94 to 2007-2008. Note that the previous study area covered the Beaufort Sea coast from Mackenzie Bay to Point Barrow and the northern portion of the Alaska Chukchi Sea coast from Point Barrow to near Icy Cape.

The specific objectives for this study are to:

1. Document and map the spatial distribution and extent of recurring leads, lead systems and polynyas along the Alaska coast of the Beaufort and Chukchi Seas and their extension into the Chukchi Sea, and develop terminology to describe and classify lead patterns;
2. Document and map the extent of the stable landfast ice along the Beaufort and Chukchi Sea coasts of Alaska and the northern coast of the Chukchi Peninsula in eastern Siberia;
3. Determine monthly mean, minimum and maximum landfast ice extents;
4. Determine and grid monthly lead and polynya occurrence probabilities;
5. Summarize statistics of lead morphology and recurrence;
6. Interpret the lead patterns and polynyas as indicators of ice dynamics;
7. Interpret landfast ice variability in the context of atmospheric and oceanic forcing and bathymetric constraints.

## Study Area

Figure 1 shows the complete study area for the current project. The Beaufort Sea study region for the landfast ice mapping is the same as the complete study area from the previous project. For the leads mapping component, we have divided the overall study region at Point Barrow.



**Figure 1. Map showing complete study area for this project with the different subregions for the landfast ice mapping and leads mapping components**

## Methods

The primary methods to identify and quantify leads and landfast sea ice are the same as those developed during the earlier project. In addition, since Radarsat data is not available after 2008, we are developing an alternative means to delineate landfast sea ice using other SAR platforms. We summarize the different methods below.

### *Lead pattern analysis*

The lead analysis addresses objectives #1, 4, 5 and 6 as outlined above. Our methodology is based on the hypothesis that there should be significant repeatability in the occurrence of those patterns. This reasoning was based on the observation that lead patterns result from the interaction of moving pack ice with the coasts of Alaska and Canada (as modified by landfast ice) under driving forces supplied by the passage of weather systems. The similarity between the boundaries and the driving forces from year-to-year (Rigor et al., 2002) creates the repeatability of the patterns, although some variations could be expected based on the properties of ice pack as a unit. The results from our previous study showed this to be the case for the Beaufort Sea



[Eicken *et al.*, 2006], where we identified several recurring lead patterns and transitions between them.

Our approach to mapping and characterizing leads and lead pattern consists of two stages. The first stage involves manual examination of AVHRR imagery for each individual day in the ice year (~September to ~July). In each image, we identify all visible leads and characterize the pattern they form. Over the course of the record (1994-2008) we identify a number of recurring patterns, which we characterize and name. Iterating this procedure, we assign the lead patterns seen in daily images to the named recurring patterns we identify. We also note occasions when the open water or thin ice delineate a seaward boundary to the landfast sea ice. In addition, analysis of daily images is used to identify cloud-free sub-regions for subsequent quantitative analysis. Scanning of the AVHRR imagery is therefore a necessary first step and provides a starting point for the remaining sections of the study.

Having created a catalog of cloud-free images and sub-regions, we acquire full-resolution calibrated imagery for the quantitative analysis of leads distributions. To identify open water in the AVHRR imagery we make the assumption that the reflectance (in the case of visible imagery) or brightness temperatures (for thermal imagery) within a land-masked image will have a bimodal distribution. That is, the sea surface is occupied by either open water or sea ice and the variability of pixel values for open water pixels or ice pixels is much less than the difference between ice and open water pixels. In this way, we use the peaks of the bimodal pixel value distribution for each image to determine what values represent ice and open water. We go further to assume that intermediate pixel values represent fractional ice concentrations. We then binarize the AVHRR image such that pixels with >25% open water are classified as leads and everything is classed as ice. Having created lead images, we apply a series of morphological filters to derive the metrics of individual leads (area, perimeter, length, width, orientation) and the overall distribution (number density, areal fraction).

### ***Landfast ice edge locations and variability analysis***

This part of the study will address objectives #2, 3 and 7 as outlined above. The seaward landfast ice edge (SLIE) detection will conform with the methodology developed for our previous project, which is based on a rigorous definition of the landfast ice that can also be applied to any remote sensing data in order to examine regional variability. The definition is based on two criteria[Mahoney *et al.*, 2007]:

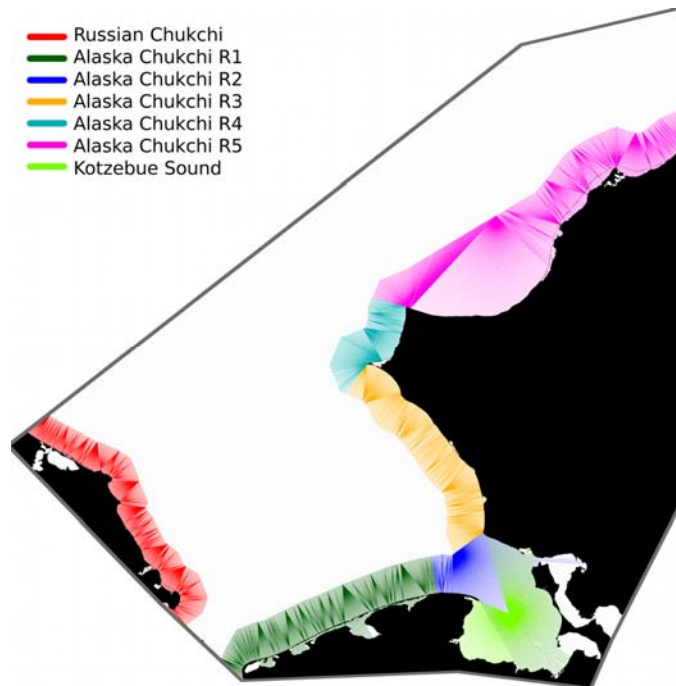
- (1) The sea ice is contiguous with the coast.
- (2) The sea ice exhibits no detectable motion for approximately 20 days.

The stationarity criterion (2) implies that a single remote sensing scene is insufficient to identify landfast ice. The time interval was chosen to be geophysically meaningful, representing a number of synoptic time periods, hence excluding sea ice that comes to rest temporarily against the edge of the landfast ice and lacks a mechanism to hold it fast. The time period was also deemed to be operationally useful for planning activities on landfast ice.

The first step in our methodology is to identify the required Radarsat data granules. To do this, we make use of the User Remote Sensing Access interface of the data archive at the Alaska Satellite Facility (ASF). We analyze the search results data coverage using GoogleEarth™ and convert the refined search results to an express search format that allows the ordering of large data volumes. Once ordered, the SAR data are geocoded into a predefined map projection using ASF's MapReady. We then create mosaics of the geocoded imagery covering the study area from high resolution ScanSAR data approximately every 10 days, with a georeferencing accuracy of 200 m.

To identify landfast sea ice, we manually examine sets of three consecutive mosaics that span a period of ~20 days delineating regions that conform to criteria (1) and (2) above. The SLIE

delineated in this fashion is a line representing the minimum offshore extent of contiguous stationary ice during the period represented by the three mosaics. To determine minimum, maximum or mean position of the landfast ice over time, we first measure the width of landfast sea ice along predefined vectors approximately normal to the coast (Figure 2). These width measurements effectively define the shape and location of each individual SLIE so that we can analyze variability in extent over space and time, as detailed in Mahoney et al. (2007).



**Figure 2. Approximately coast-normal vectors used to define the position of the SLIE in terms of the landfast ice widths at fixed locations along the coast.**

### *Alternative approaches for deriving SLIE locations and landfast ice stability*

The approach outlined below will explore an alternate approach to achieving objectives 2, 3 and 7 (Section 3.1) of our study. Since the completion of the previous project a new promising method for detecting the landfast ice edge has emerged. This method uses interferometric image pairs acquired by the spaceborne L-band SAR sensor PALSAR on board the Japanese Advanced Land Observing Satellite (ALOS) for delineating the stationary regions of the sea-ice cover.

In SAR Interferometry (InSAR), pairs of SAR images acquired with a time difference of 20 to 50 days are combined and the signals captured by the two images are compared. Interferometric coherence indicates areas in the images that remained unchanged within the observation time, while the interferometric phase reveals information about cm- to dm-scale ice motion as well as shear and stress phenomena. SAR data has the ability to penetrate clouds and map the earth's surface independent of weather conditions and during both day and night. Therefore, it has a notable advantage over data acquired in the visible part of the spectrum.

The potential of InSAR for sea ice observation was limited in the past as most spaceborne sensors operated at C-band frequencies. At this frequency range the observed signal is strongly

dominated by surface and near surface scattering, causing the data to be very sensitive to changes of the sea-ice surface conditions. Therefore, even subtle variations in the top ice layers, e.g., as a consequence of snow drift or desalination, cause the interferometric coherence to drop rapidly, prohibiting a detailed analysis of the landfast ice extent. However, with the launch of ALOS PALSAR in 2006, InSAR data in L-band has become routinely available. L-band signals penetrate much deeper into the ice body, thereby reducing the influence of surface changes on the interferometric coherence and enabling the mapping of the land fast ice area. First analyses of PALSAR interferometry-based landfast ice detection over the Beaufort and Chukchi Sea have been conducted and yielded very promising results.

Within this project, the potential of PALSAR data for monitoring the landfast ice conditions and extent throughout the sea-ice season and across the area of interest has been analyzed and quantified using a large archive of available data. Figure 4 shows the availability of InSAR data for the 2007/08 sea ice season for the area of interest. The entire region is covered with several interferometric pairs. New SAR images are acquired in 45-day repeat cycles. InSAR results have been evaluated in comparison to standard approaches and the potential of InSAR for reducing data needs, increasing reliability of landfast ice detection, and for extracting additional information such as on grounded ridges has been assessed. Results from this analysis have been summarized in a manuscript that is slated for submission to a scientific journal (Meyer et al., Mapping Arctic landfast ice extent using L-band synthetic aperture radar interferometry, in prep.).

## **Results**

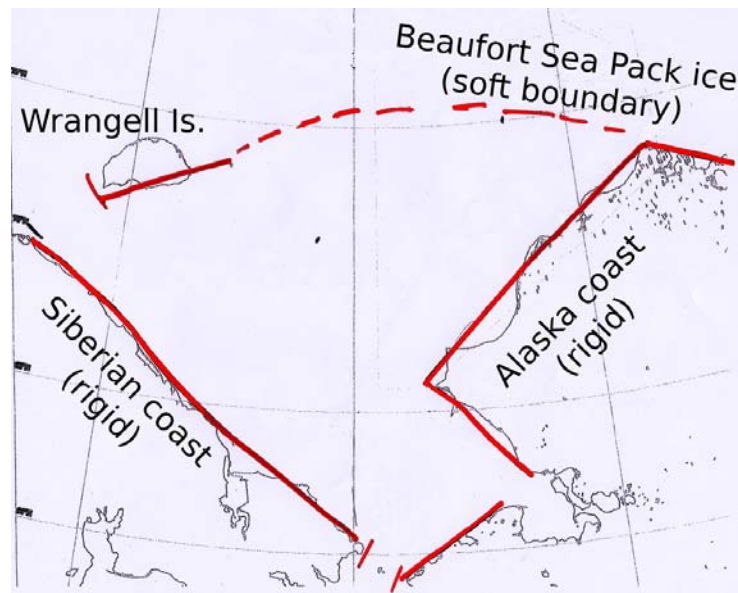
### ***Leads analysis***

A preliminary analysis of clear- or mostly clear-sky AVHRR images of the Chukchi Sea between 1994 and 2004 has now been completed. For the purposes of describing the ice cover and ice motion, the Chukchi Sea can be visualized as a roughly triangular-shaped, confined basin. The coasts of Alaska and Siberia can be thought of as two rigid boundaries of this triangle converging toward Bering Strait. The third and largest side is comprised of a “soft” boundary formed by the Beaufort Sea ice pack and another rigid segment formed by Wrangell and Herald Islands the landfast ice between them. These boundaries are illustrated in Figure 3.

Bering Strait and the space between the Siberian coast and Wrangell Island are gaps through which ice can enter or leave the Chukchi Sea. During southerly winds, the Chukchi ice pack can be driven north into the Beaufort Sea, but motion is limited by typically high ice concentrations, which is why we consider this to be a soft boundary. Under northerly winds, floes break away and leave the Beaufort Sea ice pack and this section of the boundary is not well defined.

Within this framework, we have identified a number of recurring classes of lead patterns caused by the largely wind-driven motion of sea ice. This work has been considerably harder and more time-consuming than previous efforts in the Beaufort Sea. The main difference is that the sea ice in the Chukchi Sea is almost always in motion and apparently in a state of continuous free drift. This is indicated by the rapid response of the pack ice to changes in wind direction as weather systems cross the area. The time of year seems to make little difference in the rate of response. Rapid changes occur at any time, even in the coldest months when the ice is strongest and ice concentrations are highest. The underlying reason seems to be that there is almost always space available for the pack ice to move into. This space is created in the form of open water mainly off the coast of Alaska where prevailing northeast winds drive the pack ice away from the coast. A more detailed comparison of lead patterns in the Chukchi and Beaufort Seas will be

forthcoming in future reports. Below we list the characteristic five lead patterns identified so far in the Chukchi Sea.



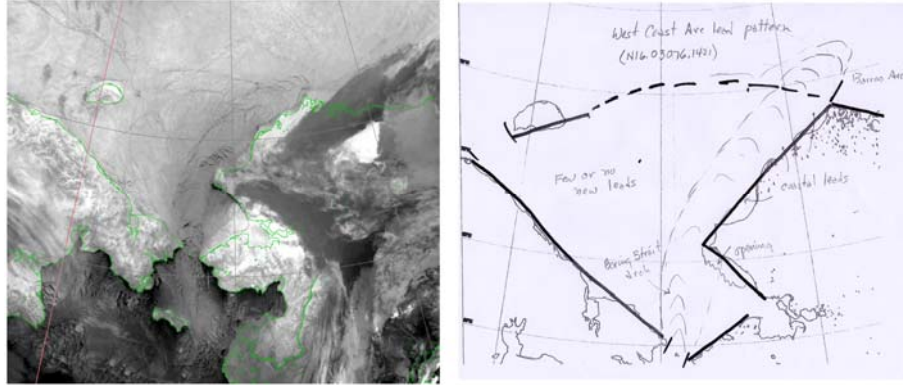
**Figure 3. Soft and rigid boundaries confining sea ice in the Chukchi Sea**

**i) Bering Strait Arch Structure**

This is a common lead pattern in the pack ice in the southern Chukchi Sea. It can form under the influence of any driving force with a northward component and therefore forms an important part of other lead patterns. This pattern is illustrated in Figure 4. The axis of the arch tends to align in the direction from which the driving force is coming, so the orientation of the arch can be a useful indicator of prevailing stress of the pack ice in this region.

**ii) West Coast Arc-Lead Pattern**

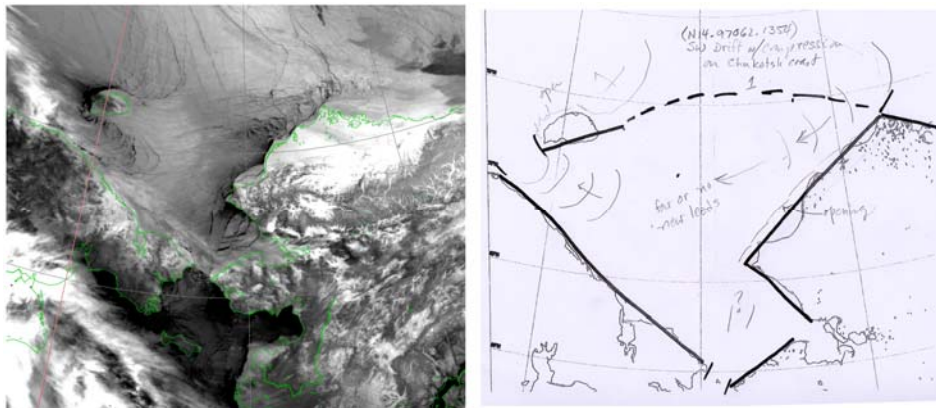
The most common feature of the Chukchi Sea ice pack (observed to date) is a zone of broken floes along the coast between Point Barrow and Point Hope, extending on toward Bering Strait. This lead pattern is illustrated in Figure 5. The width of this zone varies and is bounded on its offshore side by a shear zone or shear lead that extends from a point on the Chukotsk Peninsula just west of Bering Strait northward to end of the zone. Typically there are few if any leads visible in the pack ice west of the bounding arc lead. This indicates that much of the pack ice is apparently in a state of convergence against the north coast of the Chukotsk Peninsula.



**Figure 4. a) AVHRR image from March 3, 1997 showing lead patterns characteristic of the West Coast Arc-lead pattern. b) Schematic illustration of important lead features**  
iii) Southwest Drift With Compression Against the Chukotsk Peninsula

If the drift direction is a few degrees to the west of the average trend of the Alaska Chukchi coast, the pattern changes from that described in ii) above. Depending on the exact drift pattern, there are a number of possible variations though the basic pattern consists of a series of concave leads arcing NW from the Chukotsk coast. There are few leads elsewhere in the Chukchi Sea and the zone of broken floes along the Alaska coast (described in pattern ii) is absent.

Off shore winds from the Chukotsk Peninsula often open leads that are sub-parallel to that coast. The new leads form progressively from the coast toward the northeast as the pack ice shifts in that direction. Usually, the amount of displacement is limited by the Beaufort Sea pack ice acting as a soft boundary so the leads do not extend far from the Chukotsk Coast. However, in extreme cases under persistent forcing, arcuate leads may extend across the zone of broken floes commonly found along the Alaska Chukchi coast (pattern ii) with eventual opening of a flaw lead along the edge of the Beaufort landfast ice.



**Figure 5. AVHRR image from March 14, 2003 showing lead patterns characteristic of the West Coast Arc-Lead pattern. b) Schematic illustration of important lead features**

iv) Southeast drift in the Chukchi Sea

This is a generally short-lived pattern in which the Chukchi Sea pack ice shifts to the southeast. In some examples, an east-west lead forms across the Chukchi Sea spanning the pack ice between Herald Island with the coast of Alaska in the area of Point Hope / Cape Lisburne.

However, whether or not such a lead forms, there will probably be no new leads further north since the pack in that area is being compressed against the coast of Alaska. Thus the lead forms in response to differential motion between the pack ice masses to the north and south of it. Ice in the southern region of the Chukchi Sea is typically able to move south either through the Bering Strait or through compression of typically thin ice.

#### v) Northwest shift along the Chukotsk Peninsula

Under northwest forcing, a pattern almost the reverse of pattern iv) occurs occasionally, including the lead cross Herald Island. Again the lead forms in response to differential motion between the southern and northern regions of the Chukchi Sea. The pack may also drift between the Chukotsk Peninsula and Wrangell Island, but its movement may be constrained by the frequent presence of grounded ice in that area. When that feature is present, the result is a triangular pattern of broken floes, rather than a smooth opening.

#### Other possible patterns

There are several other possibly definable “patterns” that are not described here. In some cases they have only been recognized a few times and the area in which they appeared was limited by cloud cover. An example is a short-lived pattern of arcuate leads, concave to the east, that has been observed mainly in openings in the cloud cover over the northeastern Chukchi Sea in a few images. While the mechanical interpretation of the origin of the leads is clear, it has not been possible to tie them to a larger pattern. Other examples are episodes of both clockwise and counter-clockwise rotations of large sections of pack ice in the Chukchi Sea. These can only be identified through comparison of sequential imagery and, again, cloud cover over the rest of the Chukchi Sea prevents them from being associated with any regional pattern.

Finally, the influence of the occasional occurrence of grounded ice masses on Herald Shoal was noted above. When present, they have a noticeable effect on the pattern of leads. However, it can be difficult to identify such an ice mass when it is surrounded by pack ice. Thus, in some years, it has not been possible to recognize the presence of grounded ice well into the melt season. In those cases, consideration of the effect on lead patterns would require re-examining the imagery for an entire winter season to determine when the ice became grounded on the shoal and decide on subsequent variations in the lead patterns that could be attributed to it. This has not been done as yet.

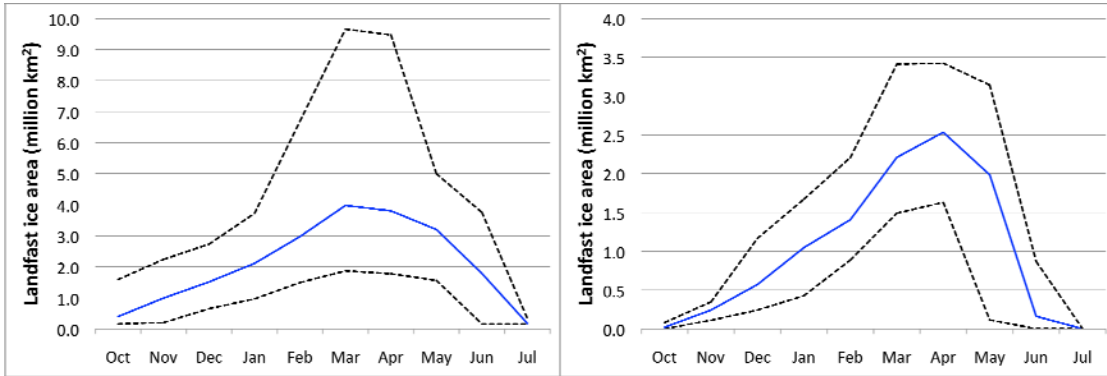
#### ***Landfast ice mapping from Radarsat data***

We are still in the stage of acquiring Radarsat data, generating mosaics and delineating SLIEs and so the following results for the landfast sea ice analysis are only preliminary.

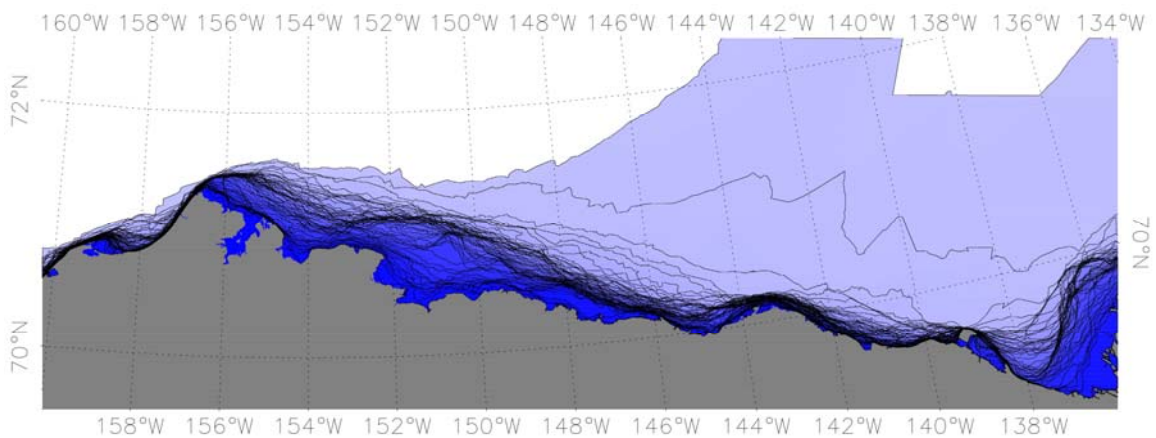
Figure 6 compares the mean annual cycles of landfast sea ice area in the Chukchi and Beaufort study regions. Figures 7 and 8 compare cumulative frequency of landfast ice area in the two study regions. Keeping in mind that we have only processed two seasons of data for the Chukchi region, these comparisons reveal general similarities between the landfast ice regimes in the two study regions. They both exhibit asymmetric annual cycles with gradual growth and abrupt retreat. Also, there are “nodes” in both regions where the SLIE occurs more frequently. They appear as clusters of SLIE lines in Figures 7 and 8 and indicate locations where the SLIE may be stabilized by grounded ice features. However, there are also differences between the Chukchi and Beaufort that are revealed even in this simple comparison. There were no large stable extensions of landfast ice in the Chukchi during the two seasons we have examined so far.

This is likely a result of the different pack ice dynamics in the Chukchi Sea and we do not expect to see large stable extensions in other seasons either.

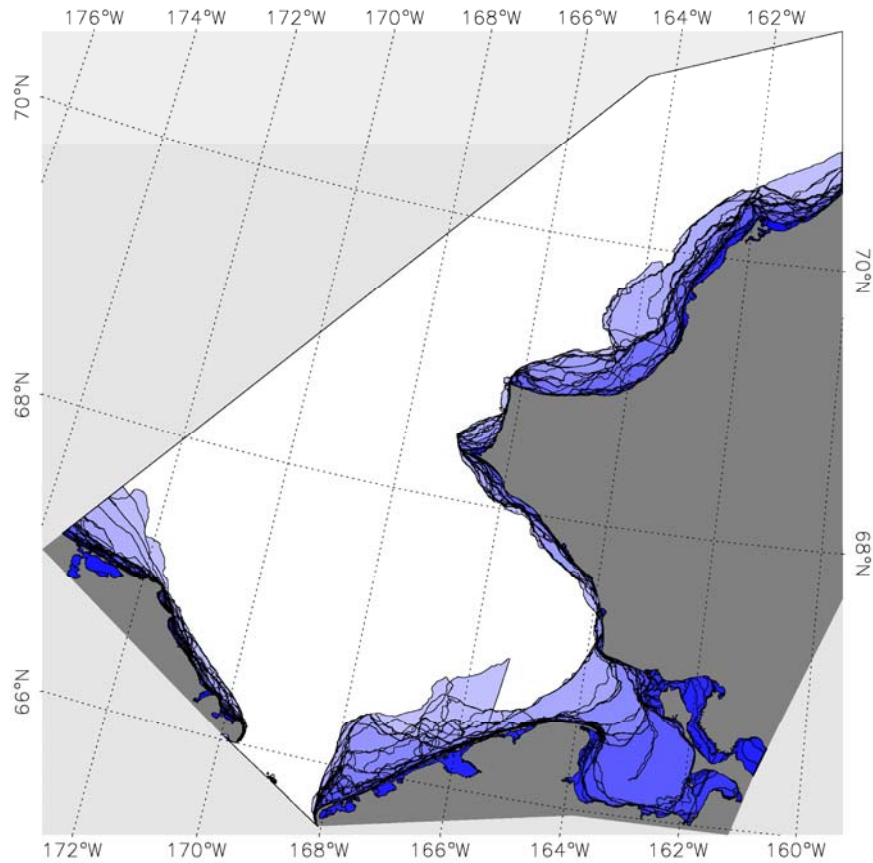
Figure 6 indicates an earlier onset of breakup in the Chukchi Sea, which is also to be expected. As we acquire more data, we will look at regional behavior in the extent and timing of landfast ice in both regions.



**Figure 6. Monthly mean landfast sea ice area (blue line) for the Beaufort Sea region from 1996-2004 (left) and the Chukchi Sea regions for 1997-98 and 2006-07. The black dotted lines above and below the blue lines show the monthly maximum and minimum areas, respectively.**



**Figure 7.: Frequency of occurrence of landfast ice in the Beaufort study region from 1996-2004. Dark blue indicated the most consistent presence, while light blue indicates infrequent occurrences. The black lines represent individual SLIEs.**



**Figure 8. Frequency of occurrence of landfast ice in the Chukchi study region from 1997-98 and 2005-06. Dark blue indicated the most consistent presence, while light blue indicates infrequent occurrences. The black lines represent individual SLIEs.**

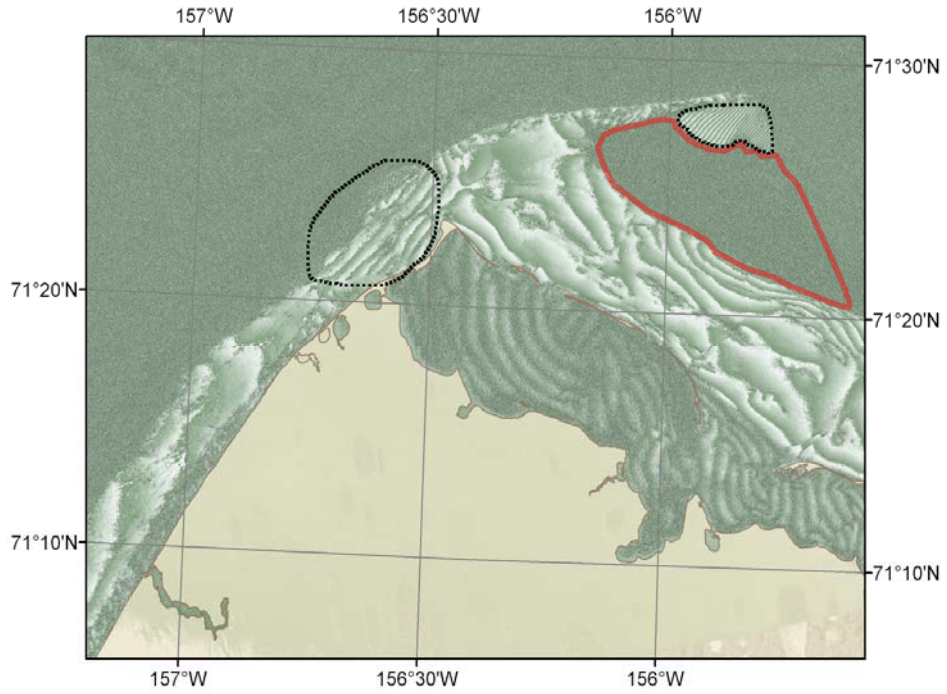
***InSAR mapping of landfast sea ice***

As of the end of 2010 we are near completion of a manuscript intended for submission to the journal *Environmental Remote Sensing* that presents our automated InSAR-based technique for landfast ice detection. Overall the results are very promising, though we identify one case where the technique was unable to identify a region of landfast ice with very low backscatter. This region is outlined in red in Figure 9 and we believe it consists of young, thin level ice. We believe cases such as this are rare and overall this technique will make a valuable contribution to the study of landfast ice around the Arctic and Antarctic.

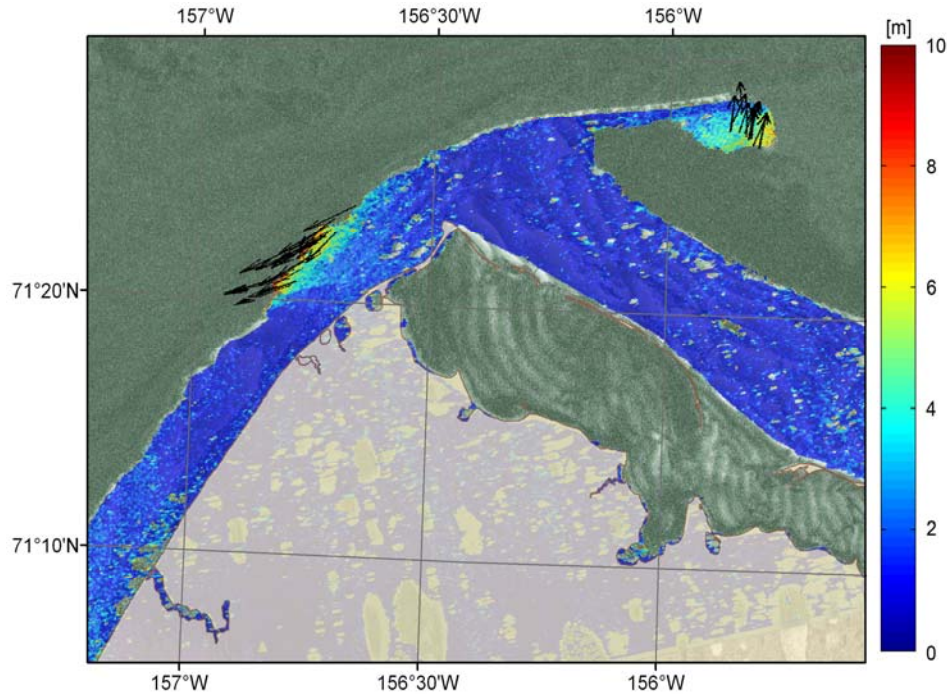
Closer examination of the interferogram identifies discontinuities in the fringe patterns, which may represent regions where the ice is grounded. The dotted outlines in Figure 9 indicate discrete regions in which the interferometric fringes are more tightly spaced, indicating small-scale relative motion in these areas. Sub-pixel cross correlation shows coherent motion within these regions of up to 10m. The magnitude and direction of these motions are shown in



Figure 10. The ability to identify regions of small-scale deformation of landfast ice from satellite data represents a potentially significant step in our understanding landfast ice dynamics and stability.



**Figure 9. Interferogram from L-band SAR images on February 6 and March 23 2008 in the region of Barrow, Alaska. The area outlined in red shows ice was probably landfast, but had such low backscatter in the SAR data that the InSAR technique was not able to calculate a coherent phase. The dotted outlines show areas of landfast ice with closer fringe spacing.**



**Figure 10. Net motion of the landfast ice derived from sub-pixel cross correlation overlain on the interferogram shown in Figure 9. The arrows indicate the direction of motion for pixels with strong cross correlation values, which are only found in the two regions with high fringe density.**

## **Discussion**

Our preliminary results indicate that the methods we developed for the earlier study are transferring well to the expanded study region, though we have had to adapt our protocols in light of issues that have arisen. The manual inspection of leads has revealed ice conditions are considerably more complex and apt to change more quickly in the Chukchi Sea than in the Beaufort Sea. In addition, cloud-free conditions are less common. Together, these differences have made it more difficult to identify recurring patterns of leads. Also, greater variability and fewer observations may degrade our confidence in the lead statistics, though this may be mitigated by the fact that we are also collecting data over a longer time period.

Analysis of the landfast sea ice data in the Chukchi Sea study region necessitated some changes to the software tools that we developed in the previous study in order to be able to cope with a discontinuous coastline. In doing so, we have added some capabilities that will allow us perform more detailed regional analyses more easily than before. However, we have encountered some difficulties in data acquisition and processing that we had not anticipated. In order to include the Russian coast in the study area, we are acquiring data from the edge of the Alaska Satellite Facility (ASF)'s station mask, which can result in poor image quality. This had meant we have to devise a strategy for preferentially layering component images in a mosaic to make best use of available imagery. In turn, this has meant data has had to be re-processed a number of times, which has created a less-than-optimal workflow for producing delineated SLIE images. As a result, we did not delineate as many SLIE images as we expected during 2010, but we are confident that these issues will be resolved in the coming year. Tables 1-4 below list the current status of data acquisition and processing for the Chukchi and Beaufort study regions.

**Table 1. Data acquisition and processing status for the Chukchi study region. Lower case y's indicate issues that will require further work / reprocessing**

Chukchi	Data Mining	Order Placed	Order Retrieved	Geocoded	Mosaiced	No. Frames Data Mined	No. Frames to order	No. Mosaics	Notes
1996-1997	Y	Y	Y	y	y	122	94	30	Some geocoding errors
1997-1998	Y	N	N	N	N	103	87	28	No data for October
1998-1999	Y	Y	Y	Y	Y	129	99	28	
1999-2000	Y	N	N	N	N	128	104	31	
2000-2001	Y	N	N	N	N	122	104	31	
2001-2002	Y	N	N	N	N	128	106	31	
2002-2003	Y	N	N	N	N	118	100	30	Only 2 mosaics in December
2003-2004	Y	N	N	N	N	127	106	31	
2004-2005	Y	Y	Y	Y	y	246	246	37	Mosaics need reprocessing
2005-2006	Y	Y	Y	y	y	229	199	31	Mosaics need reprocessing; some geocoding errors
2006-2007	Y	Y	Y	Y	Y	231	188	31	
2007-2008	Y	Y	Y	N	N	169	133	21	

**Table 2. Data acquisition and processing status for the Chukchi study region Lower case y's indicate issues that will require further work / reprocessing**

Beaufort	Data Mining	Order Placed	Order Retrieved	Geocoded	Mosaiced	No. Frames Data Mined	No. Frames to order	No. Mosaics	Notes
1996-1997	Y	Y	Y	Y	Y			27	Complete (Previous study)
1997-1998	Y	Y	Y	Y	Y			26	Complete (Previous study)
1998-1999	Y	Y	Y	Y	Y			26	Complete (Previous study)
1999-2000	Y	Y	Y	Y	Y			28	Complete (Previous study)
2000-2001	Y	Y	Y	Y	Y			25	Complete (Previous study)
2001-2002	Y	Y	Y	Y	Y			33	Complete (Previous study)
2002-2003	Y	Y	Y	Y	Y			27	Complete (Previous study)
2003-2004	Y	Y	Y	Y	Y			26	Complete (Previous study)
2004-2005	Y	Y	Y	Y	Y	246	246	30	Complete
2005-2006	Y	Y	Y	y	y	229	199	31	Geocoding errors on 7 mosaics
2006-2007	Y	Y	Y	Y	Y	231	188	31	Complete
2007-2008	Y	Y	Y	Y	Y	169	133	21	Complete

**Table 3. SLIE processing and database status for the Chukchi study region**

Chukchi	SLIE Delineations	No. SLIEs	Shapefiles	Grids	Entered into Geodatabase	Uploaded to web site	Notes
1996-1997							In progress
1997-1998							
1998-1999	Y	28	Y	Y	Y	Y	Complete
1999-2000							
2000-2001							
2001-2002							
2002-2003							
2003-2004							
2004-2005							In progress
2005-2006							
2006-2007	Y	29	Y	Y	Y	Y	Complete
2007-2008							

**Table 4. SLIE processing and database status for the Chukchi study region**

Chukchi	SLIE Delineations	No. SLIEs	Shapefiles	Grids	Entered into Geodatabase	Uploaded to web site	Notes
1996-1997	Y		Y	Y	Y	Y	Complete; Previous study
1997-1998	Y		Y	Y	Y	Y	Complete; Previous study
1998-1999	Y		Y	Y	Y	Y	Complete; Previous study
1999-2000	Y		Y	Y	Y	Y	Complete; Previous study
2000-2001	Y		Y	Y	Y	Y	Complete; Previous study
2001-2002	Y		Y	Y	Y	Y	Complete; Previous study
2002-2003	Y		Y	Y	Y	Y	Complete; Previous study
2003-2004	Y		Y	Y	Y	Y	Complete; Previous study
2004-2005	Y	28	Y	Y	Y	Y	Complete
2005-2006							In progress
2006-2007	Y	27	Y	Y	Y	Y	Complete
2007-2008	Y	19	Y	Y	Y	Y	Complete

**Study Products**

Preliminary results from this project were presented at the Coastal Marine Institute annual review on November 15. In addition, we have submitted an abstract for a presentation at the Alaska Marine Science Symposium in Anchorage, January 18-20, 2011. We presented a talk on the project at the 2010 Alaska Marine Science Symposium and to a briefing of a high-level delegation from the USGS visiting Alaska in September 2010. Project results were also presented and compared with model simulations by Wang et al. at the US-Canada Oil and Gas Forum in Calgary, Alberta in November 2010.

Also, as an amendment to the original agreement and at the request of the Bureau of Ocean Energy Management (BOEM), we carried out a literature review concerning the physical impacts of icebreakers on the sea ice. This review was submitted to BOEM on August 31.

## **Acknowledgements**

This work was supported by a grant from the Bureau of Ocean Energy Management Regulation and Enforcement (BOEMRE) through the Coastal Marine Institute (CMI project NOFA MMS09HQPA0004T) with matching funds from Conoco-Phillips and Shell.

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- Mahoney, A., H. Eicken, A. G. Gaylord, and L. Shapiro (2007), Alaska landfast sea ice: Links with bathymetry and atmospheric circulation, *Journal of Geophysical Research-Oceans*, 112(C2) C02001, 10.1029/2006jc003559.

# Subsistence Use and Knowledge of Beaufort Salmon Populations

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**Cooperative Agreement Number: M09AC15378**

## Abstract

The designation of the entire Outer Continental Shelf (OCS) of the Beaufort Sea as Essential Fish Habitat for Pacific salmon populations combined with local observations of increasing numbers of salmon in subsistence fisheries has generated a need for more information about salmon use, distribution, and survival in the North Slope region. This study addresses this knowledge gap by synthesizing relevant research and conducting ethnographic fieldwork with Inupiat informants about changing salmon populations. This study will provide a better understanding of the human and ecological environments that could be potentially affected by offshore oil and gas development in the Beaufort Sea.

## Introduction

In 2005, the National Marine Fisheries Service (NMFS) designated the entire Outer Continental Shelf of the Beaufort Sea as Essential Fish Habitat (EFH) for the five species of Pacific salmon (chinook [*Oncorhynchus tshawytscha*], coho [*O. kisutch*], pink [*O. gorbuscha*], sockeye [*O. nerka*], and chum [*O. keta*]). This EFH designation requires the Minerals Management Service, now Bureau of Ocean Energy Management, Research and Enforcement (BOEMRE), to consult with NMFS to assess the impacts of potential oil and gas development on local salmon habitat. However, little information has been documented about salmon distribution and habitat use in this region. Although, historically this region did not support viable salmon populations (Craig 1989, Fechhelm and Griffiths 2001), as climatic changes continue and winters warm in this region, the distributional range of salmon present and spawning areas appear to be expanding. Pink and chum salmon have been observed in recent years in the Beaufort Sea, Colville River, and other novel regions across the Arctic (Bendock 1979, McElderry and Craig 1981, Craig and Haldorson 1986, Babaluk et al. 2000). In addition, fall subsistence fisheries for these species have been noted in the Colville and Itkillik rivers (George 2004, cited in BLM 2007). Local residents have recently noted increasing numbers of salmon present in their subsistence fisheries, suggesting the potential of viable spawning stocks. Previous studies have not conclusively documented juvenile life stages or spawning areas present in this region; however, Fechhelm and Griffiths (2001) suggest that a few isolated spawning populations of chum and pink salmon may occur in the Colville and Sagavanirktok rivers based on their survey of Beaufort Sea salmon (BLM 2007).

Through ethnographic research with Inupiat experts, this project addresses this gap in knowledge of the status of salmon populations in local rivers and streams and along the Beaufort Sea coastline. This information will assist BOEMRE and NMFS in assessing any potential impacts on

EFH and Inupiat subsistence in this region. This research draws on theoretical and empirical studies in the anthropology of climate change and traditional ecological knowledge and contributes to scholarship in these fields.

## **Objectives**

As local ecological factors are changing in this region, local elders and fishermen are among the most knowledgeable sources of information concerning salmon distribution. This study documents the historic and current importance of salmon as a subsistence resource and also contextualizes salmon among the suite of subsistence resources in this region. The specific tasks and objectives of this project are to:

- (1) Establish strong rapport with local community residents and regional experts.
- (2) Document the current subsistence use of Beaufort Sea salmon populations in Barrow, Nuiqsut, and Kaktovik or Atqasuk.
- (3) Document the local and traditional ecological knowledge of historic and recent trends in salmon use, abundance, and distribution.
- (4) Better understand the Inupiat context for ecological observations and appropriate uses of such knowledge.
- (5) Use spatial and ethnographic data to identify streams and coastal areas where salmon have been harvested or observed.

We hypothesize that the increased presence of salmon in the region will be related to an increased importance of salmon to Inupiat communities. We also predict that knowledge about salmon in the region will be contextualized in a broad network of environmental knowledge accumulated over long time periods of close interaction between local people and their surroundings, transmitted through oral history. Knowledge about salmon is likely to be closely related to knowledge about changing ocean, coastal, river, lake, habitat, and climatic conditions.

## **Study Area**

Interviews for this project have taken place in Barrow and Nuiqsut, and will also include the community of Kaktovik. Discussions of subsistence harvest areas and observations have spanned across the North Slope region.

## **Methods and Status**

During Year 2 of the project, we have developed relationships with the Native Village of Barrow, the North Slope Borough, Alaska Department of Fish and Game, the Inupiat Heritage Center, and the Inupiat Community of the Arctic Slope. We have received formal project endorsement from the Fish and Game Management Committee of the North Slope Borough (June 2010), the Native Village of Barrow (July 2010), and the Native Village of Nuiqsut (December 2010). We are continuing to build relationships with the Kuukpik Subsistence Oversight Panel in Nuiqsut and the Native Village of Kaktovik. We have finalized an annotated bibliography of literature relevant to this project. This review covers four thematic areas: climate change, fisheries biology, North Slope subsistence practices, and traditional ecological knowledge, with a focus on Inupiat regions. In the final stages of editing, the annotated bibliography and accompanying Endnote library will be submitted along with the first quarter progress report in 2011.

The project team conducted a planning visit to Barrow from June 1-4, 2010 and conducted field research from July 6-27, 2010. We conducted 16 audio-taped interviews with key informants. We identified key informants based on recommendations from the Native Village of Barrow and the North Slope Borough, Department of Wildlife Management, and subsequently used referral, snowball sampling methods to identify additional informants. We have 10:05:47 of audio that has been professionally transcribed by a contractor (completed in January 2011). The Inupiat Heritage Center expressed interest in archiving copies of interviews conducted with elders, as their collection of fishing-related interviews is sparse. Each elder that we interviewed agreed to make their tapes available to the Inupiat Heritage Center archives for future generations. In addition to key informant interviews, we conducted informal interviews, visited fishing spots, observed and participated in fishing practices, and took part in community events. We hired two local translators in Barrow who participated in interviews with elders who preferred to speak in Inupiat. These interviews have been translated and transcribed by one of our translators.

Project PI visited the community of Nuiqsut from December 13 through 16, 2010. Introductory meetings were held with the Native Village of Nuiqsut staff and available council members and the Kuupuk Subsistence Oversight Panel staff. The IRA Council members of the Native Village of Nuiqsut each voted to endorse the project. An informant list was compiled, potential advisors and translators identified, and plans for a return research trip in February 2011 planned.

## **Preliminary Results and Discussion**

We have not yet conducted the systematic qualitative data analysis of our interview data. Our contractor delayed the completion of the transcriptions until January 2011. We have received the full transcripts of our interviews, and full translations of our interviews conducted in Inupiaq. We will begin coding and analyzing our interview data in Atlas.ti in the first quarter of 2011. From an initial review of our fieldnotes, we expect to be able to provide a description of: subsistence fishing practices, salmon use as a subsistence resource, trends of salmon abundance, geographic occurrence of salmon, local reflections on the importance of fishing for sharing and concern about commercial fishing development, weather and environmental changes that affect fishing practices or processing, Inupiat contexts for ecological observations and appropriate uses of such knowledge, and subsistence transitions over time.

### ***Use and knowledge of salmon***

Our interviews have confirmed that, while present, salmon were not a traditionally important subsistence food. One informant said: *“I never ate salmon until I went into the military. Now it’s a big thing, everybody is going for salmon.”* Some elders recalled that people have always caught salmon occasionally.

Pink (*Amaqtuuq*) and chum (*Iqalugruaq*) salmon currently make up the majority of salmon caught near Barrow. The primary spots for catching these fish are in Elson Lagoon with set gillnets. Several informants stated that before the road to Niksiuraq, people did not set nets in the lagoon. Net fishing began in the 1980s. As many as 20 to 30 individuals set gill nets in Elson Lagoon to catch subsistence fish, including salmon.

King (*Iqalugruaq*, same Inupiat name as chum) salmon are noted as increasingly common, although the abundance appears to vary greatly by year. One informant noted that about seven years ago they were catching 2-3 king salmon every day in their nets. Casting for kings has also become more common in recent years. One informant told us that the first person to cast for king salmon in Barrow was a man visiting from Oregon about a decade ago. The practice has since



caught on with locals. Other species' abundance also varies year to year. For example, in 2008, fishermen caught a record number of pink salmon in Elson Lagoon (20,000). We expect to be able to triangulate these abundance recollections with data from the NSB Wildlife Department.

Sockeye and coho salmon species have no name in Inupiaq. One informant with detailed notes of each day of his fishing catches for the past decade detailed catches of sockeye salmon, but a local biologist warned us that even the most expert fishermen in Barrow often misidentify salmon species.

Informants mentioned seeing salmon (chum, pink, king) with eggs, but no informants mentioned any knowledge of spawning or overwintering areas.

Knowledge about salmon and processing techniques appear to be incrementally developing year after year. Informants consistently articulated concerns about identifying species; however, more experienced fishermen state that newcomers are most in need of help with identification. As noted above, however, local biologists suggest that salmon species identification is problematic for all local fishermen (contrasting to very detailed abilities to detect species and even sex of whitefish species). Informants mention no traditional processing of salmon. Nowadays they are processed fresh (fried, boiled, or baked) or frozen. One informant mentioned that he learned recently how to smoke and dry salmon so that he can keep his freezer space free.

### ***Perceptions of salmon***

Several informants noted that pink salmon are considered a pest species that clog fishing nets. Informants noted:

*“We got so many pinks we ran out of freezer space.”*

*“I didn’t set my nets last year, because they kept getting clogged up with pinks.”*

*“In years when there are a lot of pinks, I’ll pull my nets because I don’t want to have to deal with too many fish.”*

Informants did not mention concern about salmon affecting the runs of other species (whitefish, cisco, Dolly Varden) as they do not overlap in time. Brewster et al. (forthcoming) discusses an informant in the 1980s that linked increasing salmon numbers to decreasing whitefish populations occurring at the time. He mentioned that the whitefish could be “scared of the salmon.” One of our informants also described salmon as the “wolves of the sea,” implying that they have voracious appetites and could have ecological impacts on the Arctic Ocean ecosystem.

### ***Geographic distribution***

We are utilizing Alaska Department of Fish and Game aerial surveys and other data to update our knowledge of salmon distribution across the North Slope area. Several informants discussed their range of subsistence activities with us using local maps. Many families retain cabins throughout the area. We have noted the bays, lakes, rivers, and areas where people have noticed salmon present and species caught if noted. We have employed a GPS unit that is being used to mark spots to generate geographic data. Several informants mentioned that releasing mapping data publically may be inappropriate, especially given concern about future commercial fisheries development as described below.

### ***Sharing and selling fish***

Many informants discussed the importance of fish for sharing. Catching fish to give them away was a primary motivation for some informants. One informant noted: *“It holds a prestige to catch more and give away and provide for a few people.”* Several informants mentioned a small-scale market for local fish. We noted a sign on one of the bulletin boards selling smelts for \$10 for a 15 gallon bag. These advertised smelts were likely from Wainwright. Resources are commonly sold or traded for between communities. One informant told us that a salmon-plate lunch will occasionally be announced for sale on the VHF radio. We heard one such announcement during our research period for a piece of salmon, rice, and a donut for \$10. Because salmon are not a traditionally valued subsistence resource and they are a commercially valued resource in most parts of the state, several informants and community members mentioned concern about the potential development of a commercial salmon fishery in the Barrow area. This is a particularly sensitive issue for many in the community that do not wish to see commercial fisheries develop in the region.

### ***Environmental changes***

Many informants discussed environmental changes related to subsistence fishing. Erosion was mentioned as a key factor affecting fishing practice. A hooked spit in Elson Lagoon, near Niksiuraq, for example, that has been there for as long informants’ memories stretch back, is no longer visible in the lagoon (documented in aerial photographs and recent pictures). Informants mention that freeze-up comes later in the year. If freeze-up does not occur until late October, for example, fish are no longer running. The late freeze-up eliminates a primary ice-fishing time period. One informant noted that water levels have been very low. Informants link these environmental changes back several decades. Several informants have noted the importance of viewing these changes as cyclical rather than directional. One informant in particular stressed that current changes should not be thought of a “new,” but rather part of processes of change that are always on-going.

### ***Identifying salmon species***

Several of our informants, as well as the Native Village of Barrow, requested help in identifying salmon species. Shelley Woods gave a presentation to the community offering tips on how to differentiate between ocean-run pink, chum, king, sockeye, and coho salmon. We also printed and distributed one-page ID guides to help fishermen identify their fish. Shelley helped to publicize the project by participating in several local radio interviews. Staff at the Barrow Arctic Science Consortium suggested that organizing a fishing derby for cod and potentially salmon to encourage youth and community fishing participation may be a nice addition to our project. Shelley is working with the University of Alaska Fairbanks, School of Fisheries and Ocean Sciences to seek funds and develop this idea further. We recognize that federal funds cannot be used to support.

### ***Concern about local relevance of project***

While many informants have appeared to enjoy visiting with us and sharing their observations of salmon and related environmental changes over time, a couple of local leaders voiced concern about the relevance of our project to local needs. This theme came up as well in a couple of interviews. Views expressed the inequities in power between local fishermen and university scientists. “We have the knowledge, we know the animals, weather, land, but we don’t have the credentials.” “We give our knowledge, you get Ph.D.s, what do we get?” While the knowledge that we collect and publish in our final report and manuscripts will be available for future generations, there was still some concerns about control of the process of the research. We heard strongly that the trend of scientists approaching a community with their own research interests is not supported. Developing research ideas and plans collaboratively was a suggested alternative.

The M.S. thesis to be developed from this project will explore these concerns in greater depth. The exploration of these issues and the thesis that results will be available for future.

## **Timeline**

As described in previous progress reports, the annotated bibliography completion was delayed. A final version of this review and Endnote library will be submitted in the first quarter of 2011. The ethnographic interview period will continue in Barrow and Nuiqsut through summer 2011. Data analysis will occur concurrently. Initial site visits and preliminary interviews in the community of Kaktovik will also be completed during this time period. Regional advisors and literature reviews have suggested that there are minimal observations and catches of Pacific salmon in this community. The project is still expected to be completed by December 30, 2012.

## **Study Products**

- Carothers, C. 2010. Climate Change and Subsistence Fisheries in Northern Alaska. Presented at the American Fisheries Society Annual Meeting, Pittsburgh, PA, September 2010.
- Carothers, C. and K. Moerlein. 2010. Climate Change & Subsistence Fisheries in Northern Alaska. Climate Change Seminar Series. University of Alaska Fairbanks, November 2010.
- Carothers, C. and S. Woods. 2010. Subsistence Use and Knowledge of Beaufort Salmon Populations (Year 2). Project report for CMI review presented at the University of Alaska Fairbanks, November 2010.
- Woods, S. and C. Carothers. 2011. Subsistence Use and Knowledge of Beaufort Salmon Populations. Poster presented at the Alaska Marine Science Symposium, Anchorage, AK, January 2011.

## **Acknowledgements**

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## **Trophic Links – Forage Fishes, Their Prey, and Ice Seals in the Northeastern Chukchi Sea**

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### **Abstract**

Oil exploration is likely to take place in the northeast Chukchi Sea simultaneously with increasing rates of global change. There is a paucity of data and limited ecological understanding for pelagic and demersal fishes in Lease Sale 193. It will not be possible to discern the extent or cause of effects on this Arctic ecosystem without first determining its current status. The rapidly receding sea ice in the Arctic has received much attention recently and record minima were recorded in three consecutive years since 2007. The loss of habitat for ice seals has resulted in two Arctic phocid species proposed for listing under the Endangered Species Act by the National Oceanic and Atmospheric Administration. Thus, not only is there a pressing need for knowledge about fishes in the Chukchi Sea, but it is also essential to evaluate those fishes as prey resources, i.e., forage, for marine mammals. We hypothesize that dietary differences among forage fishes in the vicinity of Lease Sale 193 may propagate into higher trophic levels such as ice seals. This research uses stable carbon and nitrogen isotopes from fishes, their stomach contents, and ice seals from 2008, 2009, and 2010 as a tool to test this hypothesis and to produce a more comprehensive picture of the trophic role of forage fishes in the Chukchi Sea. Trophically relating fishes and their prey to ice seals and their diets in the Chukchi Sea is essential to understanding this ecosystem.

A few modifications have been made to our original proposal, and progress continues in agreement with the proposed timeline with only slight delay. Due to the larger selection of samples obtained during 2010, seal and fish samples will be analyzed from that year rather than 2007. We eliminated three of the fish species that we had proposed to study, either because seals do not eat them or because of insufficient quantity of samples. An eelpout species that had been considered to be a non-key species for examination in a single year is important in seal diets and sufficient numbers samples are available to examine in each of three years. Stable isotope

analysis of fish and seal samples is ongoing. Fish stomach identification has been concluded for 2009 collections, and will continue during 2011 for fishes caught in 2008 and 2010.

## Introduction

The northeast Chukchi Sea from Point Hope to Barrow is undergoing increased oil and gas resource survey and development pressure. From the early 1990s until recently, the Chukchi Sea did not receive as much attention from BOEMRE as did the Beaufort Sea. However, that dramatically changed in February 2008 with Lease Sale 193 and 488 blocks were leased within the Chukchi Sea Planning Area (Figure 1). Lack of recent baseline data for fish species in the Chukchi Sea is compounded with climate change. It will not be possible to distinguish between natural and anthropogenic effects without high-quality baseline data. Thus, it is critical to assess the distribution and abundance of fishes in the Chukchi Sea prior to oil exploration or development of commercial fisheries.

Understanding potential effects of climate change or oil and gas exploration in Lease Sale 193 requires investigating trophic links between Arctic fishes and their prey and between the fishes and their ice seal predators. This will entail examining a variety of fish species, life histories, and life stages. Feeding styles of Chukchi fishes are diverse. As the Arctic ecosystem changes, fish diets will likely change. Not only is there a pressing need for knowledge about fishes in the Chukchi Sea, but also it is essential to evaluate those fishes as prey resources for marine mammals. The rapidly receding sea ice in the Arctic has received much attention recently and record minima were reported in 2007, 2008, and 2009. For many marine mammals in the Arctic, sea ice is an important platform for resting, mating, and pupping. In response to significant sea ice habitat loss and reduced snow cover, the National Oceanic and Atmospheric Administration's (NOAA) Fisheries Service is currently proposing to list four subspecies of ringed seals (*Pusa hispida*), including the Arctic Basin population, and two distinct population segments (DPS) of bearded seals (*Erignathus barbatus*), of which one is the Beringia DPS, encompassing the Bering, east Siberian, Chukchi, and Beaufort seas as threatened under the Endangered Species Act. Ribbon (*Histiophoca fasciata*), and spotted seals (*Phoca largae*) were also proposed for listing. However, NOAA concluded that spotted seals are less ice dependent than the other seal species and are more likely to adapt to life on land or migrate to better habitat. As for ribbon seals, NOAA concluded that sufficient sea ice would remain in ribbon seal habitat by the end of the century. Thus, the Bush and Obama administrations announced their decision not to list spotted or ribbon seals at this time. Potential listing underscores the need to learn as much as possible about ice seals in the vicinity of Lease Sale 193, including trophic linkages with forage fishes.

Stable nitrogen and carbon isotope analyses of animal tissues are used frequently to examine the structure of food webs and to determine food sources. There is concern in the stable isotope research community on how to treat variability of stable isotope ratios in sample material and potential sources of error, one such error being the variable lipid content in sample tissues (Sv aranta and Rautio 2010). Lipids are depleted in the heavier carbon isotope ( $^{13}\text{C}$ ) and increases in tissue lipid content could result in lower  $\delta^{13}\text{C}$  values, even when the source of carbon from diet stays constant (McConnaughey and McRoy 1979). Lipids can be removed prior to stable isotope analysis to remediate this bias; however, chemical lipid extraction can alter nitrogen ratios thus confounding important trophic level information (Sweeting et al. 2006). An alternative to lipid extraction is mathematical correction of carbon values. The greater amount of lipids within a sample has been demonstrated to be closely related to higher C:N ratios (McConnaughey and McRoy 1979). Previous models to correct for carbon assume a non-linear relationship (McConnaughey and McRoy 1979; Kiljunen et al. 2006; Logan and Lutcavage 2008), though a linear relationship between the C:N ratios and difference in  $\delta^{13}\text{C}$  of non-lipid-

extracted and lipid-extracted samples has been documented for aquatic organisms (Post et al. 2007). Treatment of samples is crucial and if improperly assessed it has the potential to introduce bias into baseline data and mixing model results.

Isotopic mixing models have become powerful tools to evaluate proportional importance of prey with different isotopic signatures (Phillips and Gregg 2003; Phillips et al. 2005; Moore and Semmons 2008; Parnell et al. 2010). In mixing model terms, prey isotope signatures are called sources, and sources combine to create a mixture, i.e., isotope signature of a predator. Models developed by Phillips and co-authors have been most commonly used. IsoError, one such program, incorporates variability of source proportions, but is constrained by the number of prey items allowed into the model, i.e., number of isotopes plus one (Phillips and Gregg 2001). IsoSource, another mixing model program, can handle multiple sources, but cannot incorporate measurement errors and sample variability of both source and mixture (Phillips and Gregg 2003). Bayesian mixing models, i.e., SIAR (Stable Isotope Analysis in R), allows for multiple dietary sources, incorporates variability of isotope signatures of source and mixture, and includes an overall residual error term; in turn, the SIAR model generates potential dietary solutions as true probability distributions (Parnell et al. 2010).

Our study will incorporate stable isotope analysis to establish trophic links within the Chukchi Sea food web. Carbon and nitrogen isotope ratios will be determined from fishes, their prey, seal muscle, seal liver, and seal claws. It is important to establish prey isotope libraries to both infer the diet of the predator and estimate contribution of particular prey species, thus enabling effective monitoring of changes over time. Updating prey libraries periodically is necessary. Most prey libraries assume that the prey does not change over time. This is most likely a glaring oversight, as it is likely that seal prey, i.e., fish, may switch their prey over time.

## **Objectives and Hypothesis**

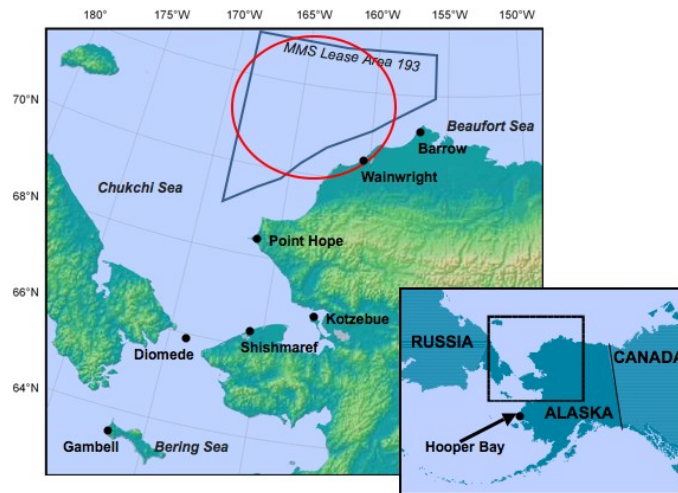
The overall project objective is to document critical baseline data on diet of forage fishes in the eastern Chukchi Sea and the trophic links from fish prey to fish to ice seals. Specific objectives include:

- (1) Determine diet composition of forage fishes
- (2) Establish trophic level of forage fish species and of their prey
- (3) Analyze interannual differences in diet of fishes and in the trophic level of fishes and their prey
- (4) Determine trophic level of ice seals
- (5) Determine ice seal trophic history
- (6) Develop isotopic mixing models
- (7) Compare trophic levels of forage fishes to those of ice seals
- (8) Provide diet and trophic level data to MMS in electronic format
- (9) Complete data archiving with National Oceanographic Data Center (NODC) and make available to BOEMRE in GIS compatible format.

We hypothesize that dietary differences of pelagic and demersal fishes among sites in the Lease Sale 193 may propagate into higher trophic levels such as ice seals. As stable isotope values of carbon ( $\delta^{13}\text{C}$ ) and nitrogen ( $\delta^{15}\text{N}$ ) are indicators of trophic level, we will use this technique to test our hypothesis by establishing a trophic relationship from prey of forage fishes through individual species of forage fishes up to ice seals.

## Study Area

Fishes available to this project were caught by bottom and midwater trawls in the Chukchi Sea and northern Bering Sea (Figure 1). Ice seal samples were collected by the communities of Little Diomede, Point Hope, Kotzebue, Gambell, Hooper Bay and Shishmaref and are on loan from the Alaska Department of Fish and Game, Arctic Marine Mammal Program (ADFG-AMMP) under permit number 358-1787. Ice-seal samples from Wainwright and Barrow were collected under the authority of permit number DWM-814-1899 issued to the North Slope Borough Department of Wildlife Management (NSB-DWM) (Figure 1).



**Figure 1. Map displays Alaskan native subsistence communities where seal samples were collected. Red circle indicates location where fish were caught.**

## Modifications to Proposal

- The proposal for this project planned for analyzing samples from 2007-2009; however, more seal samples are available from 2010 than 2007 (Table 1). Thus, the project will focus on fishes and seals caught during 2008-2010 for stable isotope and diet analysis, with the exception of one fish species, saffron cod (*Eleginus gracilis*), that was only available from 2007 collections.
- Polar eelpout (*Lycodes polaris*) had been proposed as a non-key species to be examined in a single year; however this species is important in seal diets and samples were sufficiently available to examine in each of three years.
- The proposal listed slender eelblenny (*Lumpenus fabricii*) instead of stout eelblenny (*Anisarchus medius*) as a key species; however, there were only two slender eelblenny from 2009 available for stomach content analysis. Because more specimens were available of stout eelblenny, we revised this to be a key species.



- Three species were removed from the list of fish species we had proposed to examine. Too few samples of walleye pollock (*Theragra chalcogramma*) were available from the study region, and hamecon (*Arctodiellus scaber*) and ribbed sculpin (*Triglops pingelii*) are not typical prey items for the seal species of interest.

**Table 1. Numerals indicate the count of individual seals for which samples have been collected and inventoried.**

	Species					
YEAR	Bearded Seal	Ringed Seal	Spotted Seal	Ribbon Seal	Grand Total	
2007	9	2	6	1	18	
2008	58	23	30	2	113	
2009	75	50	82		207	
2010	79	54	8	3	144	
Grand Total	221	129	126	6	482	

## Methods

Throughout the year, fishes from cruises in 2009 were processed at the Fisheries Oceanography Laboratory by taking length and weight, removing otoliths and stomachs, and recording information into a dissection log. Fish processing has been underway for fishes collected in 2010 and will continue into 2011. Approximately 220 and 880 fish specimens are planned for stable isotope and diet examination, respectively. Bearded, ringed, and spotted seals were sampled during Alaskan Native subsistence harvests that occurred mainly in June and July of 2008, 2009, and 2010. Few samples of ribbon seals were accessible, as this species has a very remote distribution in the frontal zone of the pack ice covering deep continental shelf waters (Simpkins et al. 2003). Additional field collections during summer 2010 were successful and added valuable specimens to this project; 79 bearded, 54 ringed, 8 spotted, and 3 ribbon seals. This extended fieldwork allowed for reaching target goal of at least 40 bearded, ringed, and spotted seal claws. Extending the sample collection into 2010 also allowed for valuable researcher-community communication, as Sara Carroll interacted with several members of the Barrow community while assisting with seal sampling, and was able to informally discuss this research with hunters and their families.

All seal samples planned for isotope analysis have been inventoried. Muscle samples from 2008 and 2009 have been processed at the isotope lab and liver samples from 2008 and 2009 have been freeze-dried. Muscle, liver, and claw samples collected this summer by ADFG are on loan and have been freeze-dried for analysis at the isotope lab. Jaws collected in Barrow this summer were simmered, teeth were extracted and cleaned, and then sent to Matson's Laboratory LLC in Montana for sectioning and mounting. Seal teeth collected in Barrow during 2009 have just been received for age estimation in the UAF Marine Mammal Laboratory by counting growth layers in the cementum of canine and postcanine teeth (Stewart et al. 1996). Tooth ages of seals collected from other communities have been received from ADFG.

During 2010, we examined the effect of lipid-removal on stable carbon and nitrogen isotope ratios of whole fishes, fish muscle, seal muscle, and seal liver. Muscle and liver were

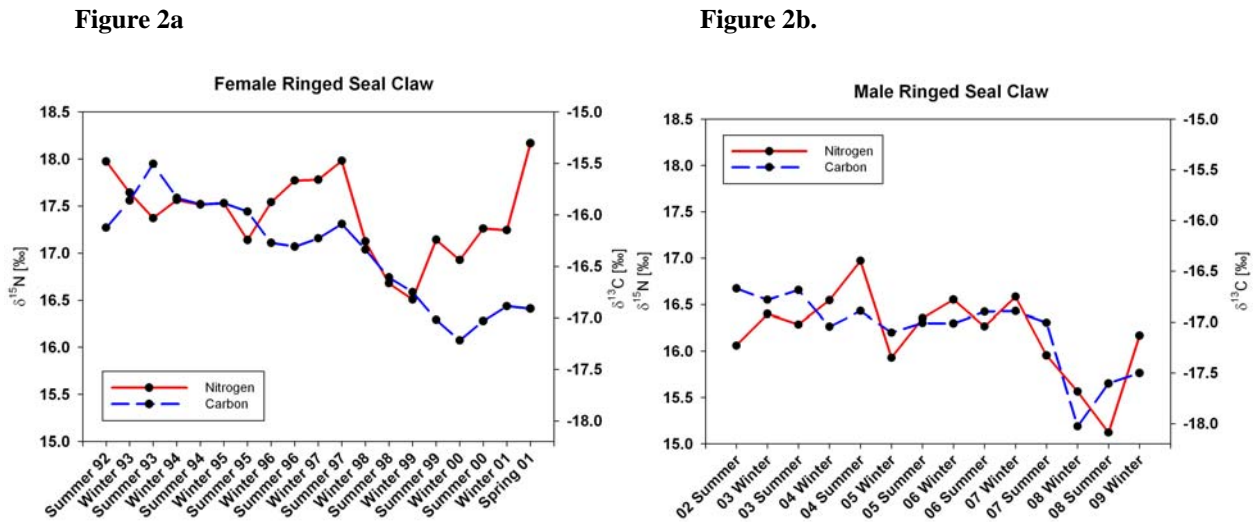
selected from 5 individuals of bearded, ringed, and spotted seals. Otoliths, stomachs, and two samples of muscle were removed from five specimens each of Arctic cod (*Boreogadus saida*), Arctic staghorn sculpin (*Gymnocanthus tricuspis*), Bering flounder (*Hippoglossoides robustus*), Capelin (*Mallotus villosus*), Pacific sand lance (*Ammodytes hexapterus*), Pacific herring (*Clupea pallasii*), Polar eelpout, saffron cod, shorthorn sculpin (*Myoxocephalus scorpius*), slender eelblenny, stout eelblenny, and rainbow smelt (*Osmerus mordax*). Whole fish, seal muscle, and seal liver samples were freeze-dried and homogenized using mortar and pestle. After each whole body fish specimen was homogenized into a powder, the sample was divided in half. One half of the whole fish was weighed directly at the Stable Isotope Laboratory at the University of Alaska Fairbanks, along with one portion of fish muscle, seal liver, and seal muscle. Lipids were removed from the remainder of whole fish, along with the other muscle sample and other portion of seal muscle and liver, by the following process. Samples were washed in a 2:1 chloroform:methanol mixture, agitated for 5 minutes in a vortex genie and centrifuged for 5 minutes at 3000 rpm. The supernatant was discarded and the process was repeated twice. The lipid-extracted samples dried overnight in the fume hood and were then re-homogenized prior to placing samples into crucibles for weighing. Homogenized samples were weighed on micro-scales at the Stable Isotope Laboratory. Carbon and nitrogen isotope ratios were analyzed using a Finnigan MAT DeltaPlusXL Isotope Ratio Mass Spectrometer (IRMS) directly coupled to a Costech Elemental Analyzer (ESC 4010); stable isotope ratios will be determined following the procedure described by Dehn et al. (2005). Impact of lipid extraction on  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  values of fish and seal tissues was tested using paired t-tests between lipid-extracted and untreated samples. Values of  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  from whole fish, seal muscle, and seal liver were incorporated into the SIAR isotope mixing model to examine potential results when using untreated prey and predator tissues, treated prey and predator tissues, lipid-extracted prey but not predator tissues, and lipid-extracted predator but not prey tissues.

Fish stable carbon and nitrogen isotope analysis and stomach identification of fish prey for 2009 fishes took place this year. Fish planned for stable isotope analysis consist of 5 individuals, over two size classes (small < 75 mm and large >75 mm), and includes a 3-year span for key species; Arctic cod, Bering flounder, Arctic staghorn sculpin, stout eelblenny, and polar eelpout. Thus far, 10 individual fish for the large size class across 12 species have been processed at the Stable Isotope Laboratory. The additional five individuals were necessary for application in the mixing model program. It is recommended by the creators of SIAR that 8-10 individual prey items per species be incorporated into the model to account for variation of stable isotope signatures within the species. The small size class for 2009, along with 2008 and 2010 fish samples, will be processed for stable isotopes in the next quarter. Stomach content identification has been concluded for 2009 fishes. Fish diet analysis encompasses 20 individuals by 2 size classes, and includes a 3-year span for key species. All 20 individuals were available for the key species in 2009, with the exception of 8 individuals for the stout eelblenny small size class, and 4 individuals for the Arctic staghorn sculpin large size class. No saffron cod, Pacific herring, and capelin were available to examine in 2009. Instead these species, along with additional Pacific sand lance, slender eelblenny, and shorthorn sculpin will be examined from 2008 and 2010 in the next quarter.

## Results and Discussions

Isotope signatures within ringed seal claws reveal foraging patterns consistent with large-scale environmental changes in prey distribution and abundance. Ringed seal claw  $\delta^{15}\text{N}$  range suggests a mixed diet of zooplankton and fish with enriched  $^{15}\text{N}$  values relating to a more extensive fish diet (Dehn et al. 2007). Stable nitrogen isotope signatures within ringed seal claws

show a negative trend starting in 2007 (Figure 2 a, b). This foraging trend may relate to an increase in feeding on crustaceans and decreased availability of Arctic cod as a result of intensified predation by sub-Arctic species (Overland and Stabeno 2004) or lower survival of juvenile fishes in relation to warmer surface water (Hop and Graham 1995) in response to climate change. Stable carbon isotope signatures within ringed seal claws illustrate a negative trend as of 2007 (Figure 2 a, b). This may relate to changes in primary production. Primary producers preferentially utilize  $^{12}\text{C}$ , but will bind and recycle  $^{13}\text{C}$  when they are trapped in brine channels in the ice (Kennedy et al. 2002). A decrease in sea ice during high photosynthetic activity will therefore lead to more depleted  $^{13}\text{C}$  signatures in open water algae compared to ice-bound algae, and this effect will propagate to predator tissues (Hobson and Welch 1992, Budge et al. 2008).



**Figure 2.** Graphs depicting the seasonal stable carbon and nitrogen isotope signatures in claws of two ringed seals. The female ringed seal (a) is a 9 year record (1992-2001), and the male (b) is a 7 year record 2002-2009. Stable isotope signatures from older keratin at tip of claw are at the left of the X-axis, with the most recent keratin deposits at the base of the claw presented at the far right of the X-axis.

Paired t-tests ( $\alpha=0.05$ ) documented a statistical significance between non-lipid-extracted and lipid-extracted seal and fish tissues. There was no significant difference for muscle  $\delta^{13}\text{C}$  values, and this was expected due to seal muscle being very lean. However, there was a significant impact on muscle's  $\delta^{15}\text{N}$  for ringed seals. Due to the importance of accurate determination of trophic level, and minimal impacts of lipids on muscle  $\delta^{13}\text{C}$  values, this project will not remove lipids from seal muscle. Seal liver  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  values were significantly altered after lipid extraction. All fish species'  $\delta^{13}\text{C}$  values were significantly different after lipid extraction. Pelagic fishes, along with shorthorn sculpin,  $\delta^{15}\text{N}$  values were significantly altered after lipid extraction. Currently, application of a mathematical correction for carbon for each species is being examined for seal livers and fishes. The ability to mathematically correct carbon values prevents nitrogen values from being impacted and saves costs and time from lipid extracting.

Biological significance of lipid removal was attested by application of data to the mixing model SIAR. For ringed and spotted seal muscle, incorporation of non-lipid extracted prey and predator muscle gave similar results when only using lipid extracted seal muscle and not lipid-extracted prey. This further emphasizes that lipid-extraction is not necessary for seal muscle. Results indicated (wrongly) more benthic foraging than typically expected for these two species (Quakenbush et al. unpublished). In contrast, ringed seals were shown as pelagic feeders and spotted seals as 50/50 mix of pelagic and benthic foragers when only lipid-extracted prey carbon and nitrogen values were used and non-treated predator muscle tissue. This comparison demonstrated these contrasting results when using lipid extracted prey and non-lipid extracted prey for ringed seals can be seen in Figure 3a, b. Hence, it is necessary to lipid-extract prey items to get an appropriate assessment of prey proportions. Individual bearded seal muscle results from the mixing models exemplify their generalist feeding style (Quakenbush et al. unpublished) and did not demonstrate a consistent pattern when treatment type was modified. Ultimately, lipid extraction of prey tissues avoids mischaracterization of ecologically significant sources. Mixing model results will continue to be analyzed to further document possible inter-annual variation, especially with the addition of 2010 samples.

Figure 3a.

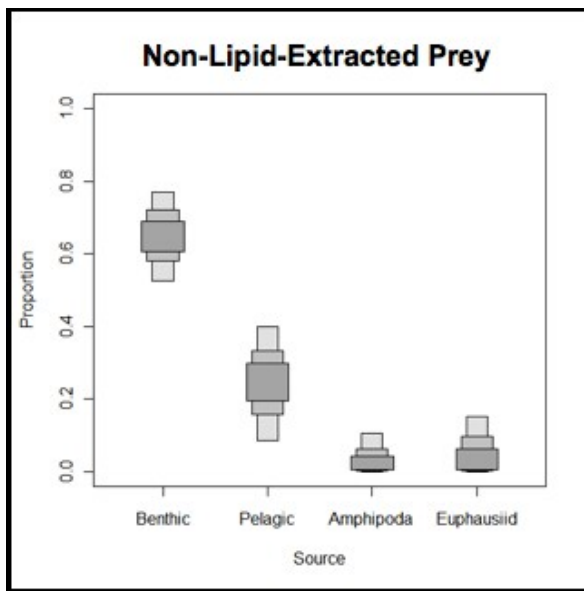


Figure 3b.

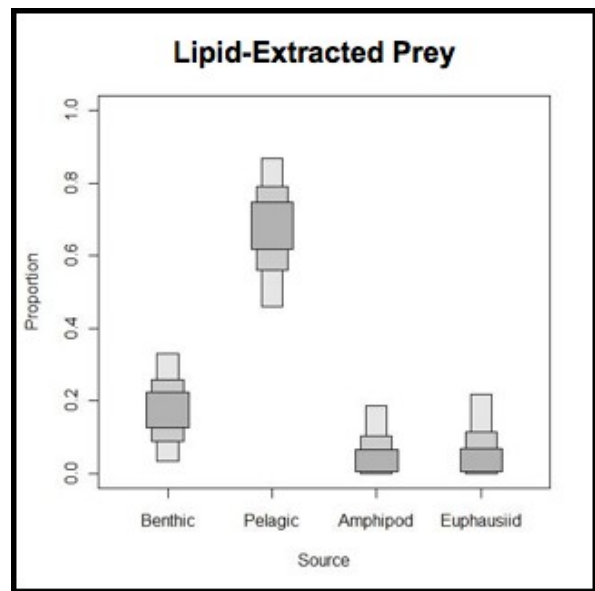
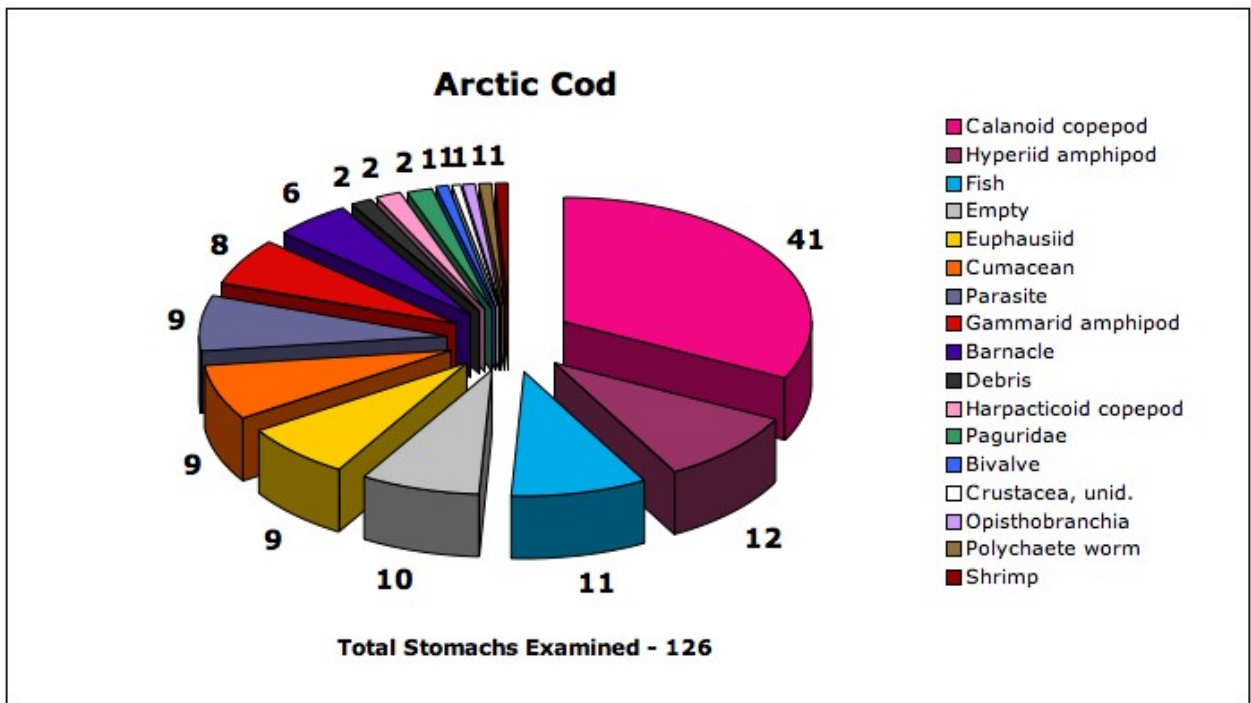


Figure 3 a,b. SIAR mixing model results of the estimated proportion of diet for ringed seals harvested in 2009 (n = 18). Y-axis is proportion of particular prey source with highest value being 100%. Box plot represents 50%, 75%, and 95% confidence intervals. Stable carbon and nitrogen isotope values for each individual predator's muscle tissue were inserted into model. Benthic category represents Arctic staghorn sculpin, Bering flounder, polar eelpout, shorthorn sculpin, slender eelblenny, and stout eelblenny as a prey grouping. Pelagic category denotes Arctic cod, capelin, saffron cod, Pacific herring, Pacific sand lance, and rainbow smelt as a prey grouping. Literature values for non-lipid-extracted amphipod and euphausiid came from Dehn et al. 2007 and Schell et al. 1998 respectively, while lipid-extracted amphipod and euphausiid literature values were used from Hobson and Welch 1992 and Iken unpublished respectively.

The most popular prey item identified in stomach contents for key fish species were gammarid amphipods, with the exception of Arctic cod. Arctic cod diet consisted of 16 types of prey and calanoid copepods were consumed by 33% of Arctic cod (Figure 4a). Arctic staghorn sculpin diet consisted of 11 types of prey and gammarid amphipods were consumed by 55% of Arctic staghorn sculpin (Figure 4b). Bering flounder diet consisted of 22 prey items and gammarid amphipods were consumed by 25% of Bering flounder (Figure 4c). Polar eelpout diet consisted of 10 prey items and gammarid amphipods were consumed by 54% of polar eelpout (Figure 4d). Stout eelblenny diet consisted of 18 prey items and gammarid amphipods were consumed by 17% of polar eelpout (Figure 4e). Stomach content identification will not be finished by the end of this year as in proposed timeline. All fish from 2010 cruise have been processed, yet some stomachs still need to be examined. In addition, 2008 key species still need to be processed.

Progress of this project has been slightly delayed. A handful of undergraduates have been helping with processing of samples for this project, along with other projects. In particular, Andrea Ruby was specifically trained and in charge of preparation of seal, fish and fish prey samples for isotope analysis while Sara Carroll processed seal claws in Seward. Over Christmas break, Andrea was tragically killed in a car accident. This has brought on a personal hardship for our lab and affected the progress of this project. Sara Carroll plans to return to Fairbanks after the Alaska Marine Science Symposium to train an undergraduate technician to complete sample preparation for stable isotope analyses.



**Figure 4a (Arctic cod).** Numeral indicates number of fish stomachs (frequency of occurrence) that contained each specified prey item. Each color represents a different prey species (see color legend for exact species). Note total number of stomachs examined is not the same for each fish species.

Figure 4b

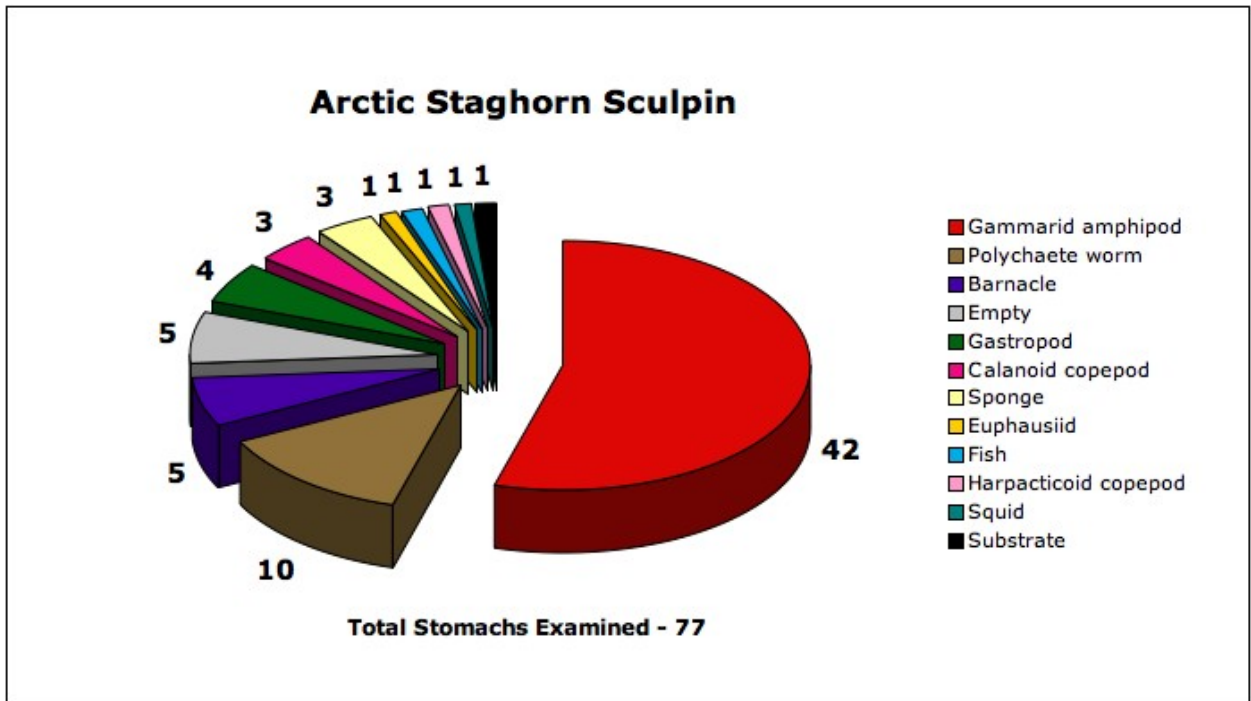
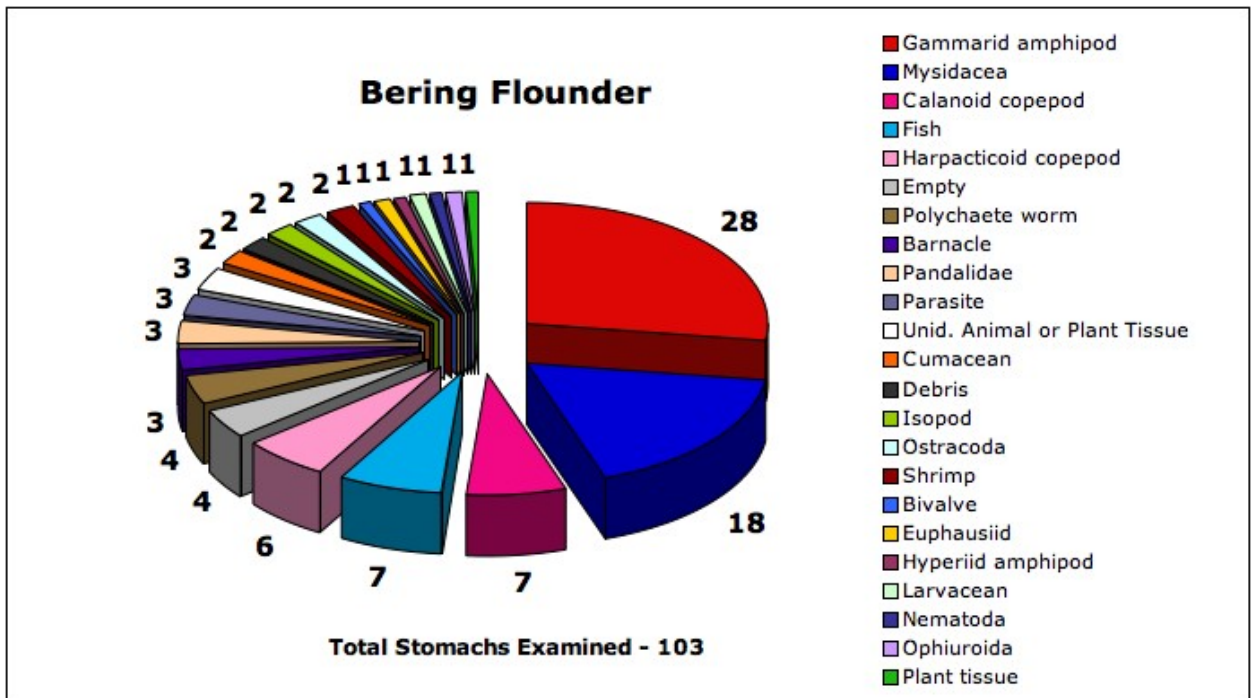


Figure 4b (Arctic staghorn sculpin) and 4c (Bering flounder). Numeral indicates number of fish stomachs (frequency of occurrence) that contained each specified prey item. Each color represents a different prey species (see color legend for exact species). Note total number of stomachs examined is not the same for each species.

Figure 4c.





## **Acknowledgements**

We thank the subsistence hunters in the communities of Little Diomedede, Point Hope, Barrow, Wainwright, and Kotzebue for making ice seal samples available for this study. We gratefully acknowledge the scientists from the University of Alaska Fairbanks and the BASIS program of the NOAA/Auke Bay Laboratory for collection of fishes, and the NSB-DWM and the ADFG-AMMP for their support with ice seal sample collections. Specifically, we thank Lori Quakenbush, Taquilik Hepa, Cheryl Rosa, Jill Seymour, Anna Bryan, Greta Krafur, and Christy Gleason for their assistance during sample collections. Fishes were caught during research cruises with funding support from the Coastal Marine Institute and Hokkaido University (OS180, OS190), the BASIS program of the NOAA/Auke Bay Laboratory (OD0710), ConocoPhillips Alaska Inc. and Shell Exploration and Production (SEPCO) (WWW0902, WWW0904), and BOEMRE (COMIDA-2009). We also thank the undergraduate technicians of the Fisheries Oceanography Laboratory/UAF for their hard work. A special thanks to Andrea Ruby, whose diligence and dedication toward this project was tremendous. She will be missed.

## **Study Products**

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# Population Connectivity in Bering, Chukchi and Beaufort Sea Snow Crab Populations: Estimating Spatial Scales of Disturbance Impacts

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## **Abstract:**

Climate trends in the Arctic appear to be impacting marine species distributions and community structure on multiple trophic levels. Superimposed upon this changing landscape are potential human impacts, including fishing pressures and petroleum resource exploration. The commercially valuable Alaskan snow crab, *Chionoecetes opilio*, has shown considerable fluctuations in population size within exploited areas of the Bering Sea over the last 25 years, and appears to be undergoing a northward range contraction due to changing climate conditions. Currently, the Bering Sea snow crab fishery is managed as a single panmictic unit; however, actual population structure, until now, was not known for this species. Moreover, snow crab stocks are essentially unexplored north of the Bering Strait, although sizeable Chukchi and Beaufort populations do exist. Knowledge of population structure and estimates of genetic connectivity between exploited and unexploited areas are critical in management decisions, and of particular importance given recent interest in resource exploration and fishing in a more ice-free Arctic. Here, microsatellite methods are used to investigate the broad-scale genetic population structure of *C. opilio* in the Bering, Chukchi and Beaufort Seas, as well as the level of differentiation that currently exists between Alaska and Northern Atlantic populations.

## **Introduction**

The snow crab, *Chionoecetes opilio*, is a widely distributed and commercially valuable species that occurs commonly in the Bering, Chukchi and Beaufort Seas around Alaska, as well as in the North Atlantic. While the Tanner crab, *C. bairdi*, is larger, faster growing, and historically more valuable than *C. opilio*, harvests for *C. bairdi* declined steadily through the 1980's and were closed from 1995 until 2008 (Bowers et al. 2008). Rapid development in the *C. opilio* fishery

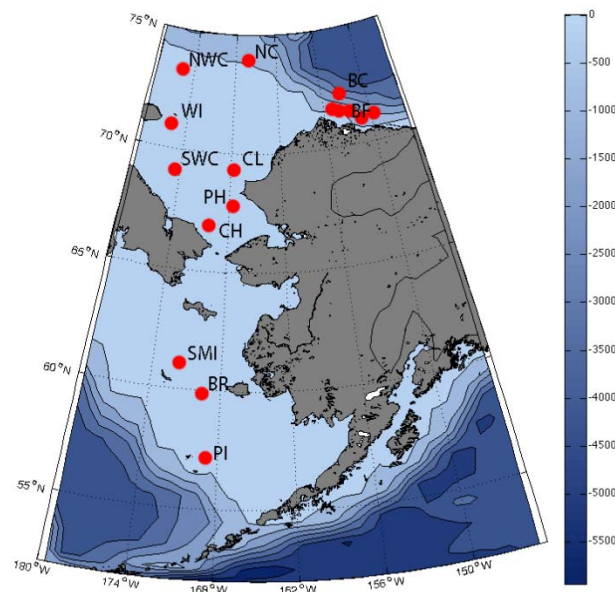
accompanied the decline in *C. bairdi*. The Eastern Bering Sea snow crab fishery is managed as one continuous population, but may extend into Russian waters to an unknown degree (NPFMC 2007). Genetic studies in both Alaskan and Canadian fishing areas point to the existence of distinct subpopulations in Tanner and snow crabs (Bunch et al. 1998, Merkouris et al. 1998, Puebla et al. 2008). Recent studies in the Eastern Bering Sea also suggest spatial separation, and possible migrations, of various ontogenetic stages (Orensanz et al. 2004, Ernst et al. 2005), as well as areas where larval retention is likely to occur due to oceanographic flow around the areas of St. Mathews Island and the Pribilof Islands (Parada et al. 2010). These patterns could be evidence for more population structure than has been accounted for in current management models.

Given the growing pressure being placed upon fisheries resources in both Alaskan and Canadian waters, the need for improved knowledge of population structure and connectivity is clear. Despite fairly thorough stock assessments in fishing-intensive areas, virtually no attention has been paid to *C. opilio* stocks in the Chukchi and Beaufort Seas (but see Paul & Paul 1997), where sizeable populations do appear to exist (Bluhm et al. 2009, Rand & Logerwell 2011). These unexplored populations may well be sources or sinks for genetic exchange with other, more intensively fished populations. The need for additional studies is increasingly pressing, given recent evidence of a declining Bering Sea snow crab population and concurrent northward range contraction, apparently due to shifting water temperature regimes in the region (Dionne et al. 2003, Orensanz et al. 2004, Lovvorn 2008). Should this northward range contraction continue, and the Chukchi Sea become the new southern limit of this species' range, any impacts of ongoing oil and gas exploration/resource development on *C. opilio* populations may constitute additional pressure on this commercially important species.

In crabs and other species with planktonic larval phases, movement away from detrimental habitat conditions and/or re-colonization of an area after a disturbance can be achieved through larval dispersal. Dispersal also constitutes a means of genetic exchange between geographically distant populations. Thus, knowledge of dispersal patterns and degrees of genetic connectivity between populations are essential in determining the spatial scales over which localized disturbances will be felt, and over which environmental impact studies should be conducted. Furthermore, directionality of dispersal may indicate sensitive areas "downstream" from impacts which need to be considered in management plans. Hydrographic flow in the study area is predominantly northward, with a 6-month transit time recorded for water parcels moving from the Bering Strait up to Barrow (Winsor & Chapman 2004). Length of the planktonic period has not been measured for snow crab at temperatures typical of the study area, but larvae could remain in the water column for several months. Thus, potential larval dispersal distances could be significant, allowing for a great deal of genetic mixing between distant populations. However, in a study of Atlantic snow crab, Puebla et al. (2008) found a genetically distinct subpopulation that was within range of larval drift, and in an area lacking obvious barriers to gene flow via dispersal. Other studies have also detected distinct genetic differentiation occurring in species with apparently continuous distributions (Taylor & Hellberg 2003, Becker et al. 2007), suggesting populations of snow crab in Alaskan waters should not be assumed to undergo continuous gene flow over their entire range.

## Objectives

We have combined genetic analysis with data from field observations of adult distributions of *Chionoecetes opilio* in the N Bering, Chukchi, and Beaufort Seas to examine population structure and spatial scales of genetic connectivity. Our overall objective was to determine whether populations are truly panmictic, given potential long-distance dispersal of larvae. Additionally, data from a similar study of snow crab in the North Atlantic are being integrated with our results, in an effort to examine larger scales of historical connectivity.



**Figure 1.** Map showing sample collection areas (red dots) with stations (*PI*-Pribilof Islands, *BR*-Bering Sea west of Nunivak Island, *SMI*-Sainte Mathews Island, *CH*-north of Chukotka, *PH*-Southwest of Point Hope, *CL*-Northwest of Cape Lisburne, *SWC*-Southwest Chukchi Sea, *WI*-Wrangell Island, *NWC*-Northwest Chukchi Sea, *NC*-North Chukchi Sea, *BC*-Barrow Canyon, *BF*-Beaufort Sea shelf. Five stations occurring close together on the Beaufort Sea shelf were pooled (station BF).

## Methods

### *Study area and sample collection*

Sampling was conducted in the Bering, Chukchi and Beaufort Seas during a series of expeditions from 2008-2010 (Figure 1). Plankton samples were also collected in the Chukchi Sea in 2007 and preserved in ethanol for future analysis of snow crab larvae. Snow crab were collected via beam trawls at 12 locations ( $n=613$ ) (Figure 1) from the Beaufort, Chukchi and Bering Seas in 2008, 2009 and 2010 respectively. Primiparous females (those within their first year of reproductive maturity) were targeted during Bering Sea sampling in order to obtain a snapshot of the mating population of female crab, because more data are available for ontogenetic migration patterns in this region (Parada et al. 2010). Segments of the 4<sup>th</sup> walking leg were preserved in 95% ethanol at the time of capture (Bering samples) or removed from whole frozen crabs at a later date (Chukchi and Beaufort samples).

#### *DNA extraction*

DNA was extracted from crab tissues using Omega Bio-Tek E.Z.N.A.<sup>®</sup> and Qiagen DNeasy<sup>®</sup> extraction kits. DNA fragments were amplified from 7 previously-developed microsatellite loci *Cop2*, *Cop3*, *Cop4*, *Cop3-4II*, *Cop24-3*, *Cop113* (Puebla et al. 2003) and ECO106 (An et al. 2007). Capillary electrophoresis was performed on a 3730 xl 96-Genetic Analyzer at the Yale University laboratory. All samples were amplified and scored independently at least two times to ensure accurate scoring of amplified fragments.

#### *Descriptive statistics and population differentiation*

Tests for departures from Hardy-Weinberg Equilibrium (HWE), and for the presence of null alleles due to stuttering or large allele drop-out were conducted using MICROCHECKER (Version 2.2.3 Van Oosterhout et al. 2004). A test for genotypic linkage disequilibrium (LD) was performed in GENEPOP (Version 4.0 Rousset 2008). To test the hypothesis of panmixia throughout the Alaska region, we used the program STRUCTURE (version 2.3.1 Pritchard et al. 2000), which employs a Bayesian clustering approach based on the Markov Chain Monte Carlo method to assign individuals to populations (clusters) based on their genotypes. The number of clusters ( $K$ ) tested within the program was set from 1-24 with 150,000 MCMC repetitions following a 75,000 repetition burn-in period using the admixture model.

To further explore genetic population structure,  $F$ -statistics including  $F_{ST}$ ,  $F_{IT}$ ,  $F_{IS}$ , observed heterozygosity ( $H_o$ ), expected heterozygosity ( $H_e$ ) and allelic richness were calculated using FSTAT (version 2.9.3.2 Goudet 1995) with 1,320 permutations. As  $F_{ST}$  has been reported to perform poorly in populations of high diversity, Hedrick's (2005) standardization of  $F_{ST}$  ( $G'$ ) and Jost's (2008) measure of true differentiation ( $D$ ) were calculated in FSTAT and the online version of SMOGD (Crawford 2010), respectively. The program GENEPOP was used to carry out pairwise comparisons of allele frequencies among sample sites and regions. Calculations were made using Fisher's exact test (Raymond & Rousset 1995) with 100 batches and 5,000 iterations.

#### *Quality control and comparison with NW Atlantic populations*

To address the requirement for third-party verification of our results, we are collaborating with Jean-Marie Sevigny of Fisheries and Oceans, Canada, who was the principle investigator on a similar study of NW Atlantic snow crab stocks (Puebla et al. 2008). Dr. Sevigny also developed six of the microsatellite loci in use for this study. The Sevigny lab performed duplicate analyses of a subset of 60 individuals from our study sites. From these data, we were able not only to verify our results, but to intercalibrate our data with those from the Puebla et al. (2008) study and perform a meta-analysis of genetic connectivity between Pacific and Atlantic populations. This analysis was based on the five loci that were amplified in both regional studies (*Cop2*, *Cop4*, *Cop3-4ii*, *Cop24-3* & *Cop113*). The difference between the raw allele scores of each individual, produced by the use of different capillary electrophoresis machines by each lab group, were averaged and used to correct the NW Atlantic dataset. Populations identified in Puebla et al. (2008) were then compared to the pooled population of Alaska region crabs using  $F_{ST}$  and  $D$  as described above to determine levels of divergence.

## Results

### *Genetic structure of Alaskan snow crab population*

Results from MICROCHECKER indicated significant departures from Hardy-Weinberg Equilibrium at 8 sample site and locus combinations out of 84 possible (9.5%). All significant tests were due to heterozygote deficits and the possible presence of null alleles; however, no more than two significant tests occurred at any site and no more than 3 were observed for any locus (Table 1). The test for genotypic linkage disequilibrium revealed 14 significant results out of 252 tests at each locus combination per site (significance level  $0.05/12=0.0042$ ). Thirteen of these 14 cases were found at the Barrow Canyon site, with the remaining case found at Saint Matthews Island. Evidence of linked loci was not evenly distributed across sites. Thus, we conclude that unusual population dynamics in the Beaufort Sea are producing this result, rather than that the loci are truly linked.

**Table 1. Summary of descriptive statistics for all loci at each site. Abbreviations of each site name (in parentheses) refer to the labels on the map in Figure 1.  $N$  = sample number; Allelic richness was calculated over all loci for each site; X indicates significant tests for deviation from Hardy-Weinberg Equilibrium.**

Sample site	$N$	Allelic Richness	$Cop2$	$Cop3$	$Cop4$	$Cop\ 3-4II$	$Cop\ 24-3$	$Cop\ 113$	$ECO\ 106$
Pribilof Islands (PI)	100	85.9		X					X
Bering Sea west of Nunivat Island (BR)	50	89.3							
Sainte Mathews Island (SMI)	50	94.3				X			X
North of Chukotka (CH)	50	88.4				X			
Southwest of Point Hope (PH)	29	88.7			X				
Northwest of Cape Lisburne (CL)	39	91.8							
Southwest Chukchi Sea (SWC)	50	89.3							
Wrangel Island (WI)	26	90.7							
Northwest Chukchi Sea (NWC)	50	95.6							
Northern Chukchi Sea (NC)	24	86.5							
Barrow Canyon (BC)	113	90.9			X				
Beaufort Sea shelf (BF)	32	88.8							X

**Table 2. Summary of statistical metrics for population structure within and among Alaskan regions.  $H_o$ , observed heterozygosity;  $H_e$ , expected heterozygosity;  $F_{IT}$ , the measure of individual diversity relative to the total population;  $F_{IS}$ , the measure of individual diversity relative to its subpopulation (in this case sampling site);  $F_{ST}$ , the measure of subpopulation diversity relative to the total;  $D$ , Jost's measure for differentiation;  $G'$ , corrected  $F_{ST}$  to account for observed levels of heterozygosity.**

Locus	# of alleles	Allele size range (bp)	$H_o$	$H_e$	$F_{IT}$	$F_{IS}$	$F_{ST}$	$D$	$G'_{ST}$
$Cop2$	24	291-341	0.834	0.837	0.004	0.004	0.001	-0.01	-0.012
$Cop3$	21	210-318	0.775	0.861	0.094	0.094	0.000	0.008	0.009
$Cop4$	12	211-259	0.257	0.284	0.128	0.131	-0.004	-0.001	-0.004
$Cop3-4II$	22	119-209	0.850	0.912	0.058	0.058	0.000	0.020	0.022
$Cop24-3$	29	145-253	0.911	0.928	0.025	0.023	0.002	0.037	0.040
$Cop113$	23	114-166	0.884	0.892	0.013	0.014	-0.001	-0.011	-0.012
$ECO106$	41	187-271	0.896	0.961	0.065	0.065	0.001	0.066	0.068
Overall	-	-	0.772	0.811	0.048	0.047	0.000	0.0159	0.0159

The Bayesian clustering analysis indicated panmixia among all Alaskan sites, based on the result that the most likely number of clusters ( $K$ ) is equal to 1. The Bayesian approach is informative in examining population subdivision over this large spatial scale in that it requires no *a priori* population assignment, but instead provides indications of sub-populations based on grouping of individuals due to similar genotypes. However, this approach tends to perform poorly when low levels of differentiation ( $F_{ST} < 0.03$  or  $G' < 0.28$ ) are present (Latch et al. 2006). We thus applied additional tests, including Wright's  $F$ -statistics. Our global  $F_{ST}$  value was extremely low ( $< 0.001$ ) compared to other northern crab populations (Beacham et al. 2008, Puebla et al. 2008). However,  $F_{ST}$  is mathematically bound by the overall heterozygosity of a population, and tends to perform poorly when heterozygosity is high (as in our target species). Hedrick (2005) and Jost (2008) developed additional measures ( $G'$  and  $D$ ) that correct for this weakness. Hedrick's  $G'$  and Jost's  $D$  were also relatively low (0.068 and 0.066, respectively; Table 2). Pairwise comparisons of  $F_{ST}$  values for all sampling sites were extremely low and resulted in no significant comparisons. Pairwise  $D$  values were relatively low; however, the Beaufort Shelf (BF) sampling site showed the largest amount of differentiation from other sites (Table 3).

**Table 3. Pairwise  $D$  values for all sample locations within Alaska region (abbreviated site names correspond to labels on the map in Figure 1).**

BR	SMI	CH	PH	CL	SWC	WI	NWC	NC	BC	BF	
.0073	0	0	0	.0045	0	0	.0003	.0003	.0024	.0036	<b>PI</b>
	.0028	0	.0038	.0025	.0108	0	.0094	.0032	.0062	.0006	<b>BR</b>
		0	0	.0100	0	0	.0018	.0013	0	.0127	<b>SMI</b>
			0	.0129	0	.0002	.0014	.0029	.0044	.0128	<b>CH</b>
				0	.0022	0	0	0	.0009	.0183	<b>PH</b>
					.0025	0	0	.0054	.0060	.0171	<b>CL</b>
						0	0	.0036	.0016	.0024	<b>SWC</b>
							0	0	0	.0011	<b>WI</b>
								0	.0017	.0110	<b>NWC</b>
									0	.0163	<b>NC</b>
										.0101	<b>BC</b>

**Table 4. Pairwise comparisons of allele frequency tests performed in GENEPOP. X indicates significant differences in frequencies ( $p < 0.05$ ).**

BR	SMI	CH	PH	CL	SWC	WI	NWC	NC	BC	BF	
-	-	-	-	-	X	-	X	-	X	-	<b>PI</b>
	-	-	-	X	-	-	-	-	X	-	<b>BR</b>
		-	-	-	-	-	X	-	-	-	<b>SMI</b>
			-	-	-	-	-	-	X	-	<b>CH</b>
				-	-	-	-	-	X	-	<b>PH</b>
					-	-	-	-	X	-	<b>CL</b>
						-	-	-	-	-	<b>SWC</b>
							-	-	X	-	<b>WI</b>
								-	-	-	<b>NWC</b>
									-	-	<b>NC</b>
										-	<b>BC</b>



Strict comparisons of allele frequencies within groups and regions can provide valuable information when addressing the question of population connectivity. Although this approach lacks a graded measure of significance, the presence or absence of a statistically significant difference in allele frequencies is a useful tool, and is not influenced by levels of heterozygosity. Allele frequency comparisons performed within GENEPOP (Fisher's method) showed that no sampling sites directly adjacent to one another were found to differ significantly in allele frequencies. Furthermore, 6 out of 10 significant differences in allele frequency (66 total comparisons) occurred at the Barrow Canyon site, indicating either population differentiation or a sampling of individuals from several populations (i.e., a Wahlund effect) (Table 4).

*Comparison with NW Atlantic populations*

Results from quality-control analysis of 60 tissue samples are summarized in Table 5. Note that each locus failed to amplify in a small subset of the samples, possibly due to poor DNA preservation through subsampling and shipping between labs. Similarity in allele scoring between labs was >95% in all cases (Table 5). Formulas for converting allele scores between labs were established from this analysis, and then applied to the Puebla et al. (2008) data set for NW Atlantic snow crab populations. We then combined Pacific and Atlantic datasets (all Alaskan samples pooled into one putative population, based on results of our analyses) and re-calculated  $D$  and  $F_{ST}$  values for all the data combined (Table 6). Significant divergence ( $F_{ST} = 0.0269$ ) was detected between the Greenland population and the mainland Canadian population, with our analysis recovering the same  $F_{ST}$  value for this comparison that was reported in Puebla et al. (2008) ( $F_{ST} = 0.027$ ). The Alaskan crab population also appears to be genetically distinct from the Greenland population, which would be expected due to the greater distance; however, Alaskan crabs show very low genetic differentiation from those in coastal Canada.

**Table 5. Results from comparative analysis of 60 samples analyzed here and in the Sevigny lab, including number of successful amplifications of each locus in the Sevigny lab (and therefore, successful inter-lab comparisons), and the level of consistency by which correct alleles were scored in both labs.**

<b>Locus</b>	<b># of successful comparisons</b>	<b>Allele scoring (% similarity)</b>
<i>Cop2</i>	48	95/96 = 98.9%
<i>Cop4</i>	48	92/96 = 95.8%
<i>Cop3-4II</i>	44	87/88 = 98.8%
<i>Cop 24-3</i>	49	95/98 = 96.9%
<i>Cop113</i>	46	88/92 = 95.7%

**Table 6. (Left)  $D$  values (Left panel) and  $F_{ST}$  values (Right panel) for pooled samples from Greenland, mainland Atlantic Canada and the pooled Alaskan sites in the Bering, Chukchi and Beaufort Seas. Xs in the right panel indicate significant divergence after Bonferroni correction ( $p < 0.0167$ ).**

	Greenland	Canada	Alaska		Greenland	Canada	Alaska
<b>Greenland</b>	-	0.1283	0.1450	<b>Greenland</b>	-	.0269	.0318
<b>Canada</b>		-	0.0087	<b>Canada</b>	X	-	.0047
<b>Alaska</b>			-	<b>Alaska</b>	X	X	-

## Discussion

We have employed a number of statistical approaches to the analysis of this microsatellite dataset in an effort to examine regional population connectivity within Alaskan snow crab stocks. In addition, through the inter-calibration of our results with those of a similar study in the NW Atlantic, we have been able to examine population differentiation on trans-Arctic spatial scale. The results of this analysis suggest that Alaskan populations are panmictic, with the possible exception of the Beaufort Sea population. Moreover, recent extensive gene flow appears to have occurred across the Canadian Arctic, between N Pacific and NW Atlantic populations, although the Greenland population appears to have been isolated from genetic exchange over longer time scales.

### *Connectivity within the Alaska region*

Our preliminary results suggest Alaskan populations of *Chionoecetes opilio* appear to be experiencing high levels of gene flow. Although aspects of snow crab life history and migration still remain unclear, evidence for a long larval dispersal phase and substantial migration by both males and females indicate extensive gene flow could occur. However, other studies of marine organisms with lengthy larval dispersal phases have shown that both panmixia and complex genetic structure are possible, and may be influenced by a number of factors including ocean circulation patterns. Although eddies in areas of the Bering Sea (Stabeno & Schumacher 1999) are shown to be areas of local recruitment (Parada et al. 2010), significant northward transport of larvae must be occurring to maintain patterns observed here. Previous work conducted on snow and Tanner (*C. bairdi*) crabs in the SE Bering Sea also suggested high connectivity; however, the sampling was limited to a small region and did not examine connectivity over larger spatial scales (Merkouris et al. 1997).

Little is known about snow crab populations within the Chukchi and Beaufort Seas. However, recent sampling efforts suggest that size at maturity is much reduced in northern portions of the range, and that multiparous females are found in relatively shallow regions several hundred nautical miles from the shelf break (Paul & Paul 1997, Bluhm 2009). Most interesting, however, is the discovery of large male crabs (>101 mm) in the deep waters (3-500m) of the Barrow Canyon (Rand & Logerwell 2011; Bluhm et al. unpublished data). Evidence of linkage disequilibrium in our Barrow Canyon (BC) samples could suggest that this local population is comprised of individuals from relatively distinct subpopulations (known as a Wahlund effect). If mating is occurring at this location, our results suggest larvae may not be recruiting back to the local population. Oceanographic patterns tend to support this hypothesis in that the flushing of the Chukchi shelf through Barrow Canyon, offshore transport into the Arctic Basin, and eastward flow into Arctic Canada (Pickart 2004, Weingartner 2005) (where snow crab are not known to

occur) may be exporting larvae out of this local system. If this population is not self-recruiting, it may be comprised of migrants from other regions, which is consistent with our observation that the Beaufort Sea shelf (BF) site was found to have the highest levels of genetic differentiation (based on Jost's D) of any of our sampling sites.

The absence of genetically distinct subpopulations within our sampling region suggests sustained influx of larvae to northern regions may provide some capacity to recover from local disturbance. However, the environmental factors that govern distribution and population dynamics in this species are still an active area of research. The group of commercial-sized crabs found in Barrow Canyon is of particular interest in considering disturbance effects. Evidence suggests that this population is a larval source that does not self-recruit, and may thus be unable to sustain any future fishing efforts.

#### *Large scale comparisons*

Our comparisons between Alaskan and NW Atlantic populations suggest that the Greenland population is the most genetically-divergent group of the three regions compared (Table 6). Not surprisingly, the level of divergence between Alaska and Greenland populations is significant. Of greater interest is the finding of low divergence between Alaskan and mainland Atlantic Canada populations, particularly given the apparent absence of this species in the Canadian Arctic. This observation suggests a recent connection and high gene flow between these two regions, although extremely large effective population sizes may also be slowing the genetic divergence between these two geographically isolated regions.

#### *Timeline*

The project is progressing roughly according to schedule, and in accordance with proposed objectives. Sample analysis is complete, and data analysis is nearing completion. The graduate student expects to complete thesis writing in spring 2011, with graduation expected in summer 2011. We expect to produce a manuscript to be submitted to a peer-reviewed journal, as well as our final project report, by fall 2011. Results were presented at the Alaska Marine Science Symposium in January 2011, and an oral presentation will be delivered to the Rasmuson Fisheries Research Center at their annual meeting in March.

### **Acknowledgements**

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## Final Reports Pending

TO/CA No.	Title	PI	Status
39953	<b>Idealized Process Model Studies of Circulation in the Landfast Ice Zone of the Alaskan Beaufort Sea</b>	<b>Thomas Weingartner</b> <i>weingart@ims.uaf.edu</i> Institute of Marine Science University of Alaska Fairbanks Fairbanks, AK 99775-7220	This report was submitted to CMI in thesis format. It is in the process of being prepared for publication.
M07AC13416	<b>Current and Historic Distribution and Ecology of Demersal Fishes in the Chukchi Sea Planning Area</b>	<b>Brenda L. Norcross</b> <i>norcross@ims.uaf.edu</i> Institute of Marine Science University of Alaska Fairbanks Fairbanks, AK 99775-7220	This report is at BOEMRE for a final review and is expected to be ready for final formatting in May or June.
39380	<b>Assessment of the Direction and Rate of Alongshore Transport of Sand and Gravel in the Prudhoe Bay Region, North Arctic Alaska</b>	<b>A. Sathy Naidu</b> <i>ffsan@uaf.edu</i> Institute of Marine Science University of Alaska Fairbanks Fairbanks, AK 99775-7220	This report is in the process of being published at CMI.
39921	<b>Synthesis of Time-Interval Changes in Trace Metals and Hydrocarbons in Nearshore Sediments of the Alaska Beaufort Sea: A Statistical Analysis</b>	<b>A. Sathy Naidu</b> <i>ffsan@uaf.edu</i> Institute of Marine Science University of Alaska Fairbanks Fairbanks, AK 99775-7220	This report is in the process of being published at CMI.

## CMI Program Funding Summary

### Student Support

The cooperative agreement that formed the University of Alaska Coastal Marine Institute stressed the need to support education, as well as research. The following student support information is summarized from proposals and may not accurately reflect actual expenditures.

Fiscal Year	Program	Students	MMS Funds	Matching Funds
1994	PhD	1	\$22,558	\$9,220
	M.S.	6	\$65,107	\$37,411
	Undergrad	1	\$4,270	\$0
	<b>Source Total</b>		<b>\$91,935</b>	<b>\$46,631</b>
1995	PhD	4	\$53,061	\$9,523
	M.S.	8	\$90,367	\$64,380
	Undergrad	5	\$4,297	\$13,933
	<b>Source Total</b>		<b>\$147,725</b>	<b>\$87,836</b>
1996	PhD	5	\$75,499	\$8,499
	M.S.	5	\$80,245	\$18,661
	Undergrad	2	\$4,644	\$0
	<b>Source Total</b>		<b>\$160,388</b>	<b>\$27,160</b>
1997	PhD	2	\$37,714	\$0
	M.S.	2	\$22,798	\$0
	Undergrad	2	\$2,610	\$0
	<b>Source Total</b>		<b>\$63,122</b>	<b>\$0</b>
1998	PhD	2	\$17,109	\$17,109
	M.S.	2	\$26,012	\$7,200
	Undergrad	2	\$0	\$2,548
	<b>Source Total</b>		<b>\$43,121</b>	<b>\$26,857</b>
1999	PhD	6	\$66,750	\$38,073
	M.S.	4	\$31,650	\$8,730
	Undergrad	4	\$0	\$10,704
	<b>Source Total</b>		<b>\$98,400</b>	<b>\$57,507</b>
2000	PhD	6	\$61,383	\$30,551
	M.S.	2	\$5,868	\$10,135
	Undergrad	7	\$0	\$21,299
	<b>Source Total</b>		<b>\$67,251</b>	<b>\$61,985</b>
2001	PhD	2	\$19,159	\$22,019
	M.S.	1	\$0	\$5,800
	Undergrad	3	\$10,983	\$5,761
	<b>Source Total</b>		<b>\$30,142</b>	<b>\$33,580</b>
2002	PhD	3	\$48,476	\$0
	M.S.	5	\$66,676	\$7,500
	Undergrad	0	\$0	\$0
	<b>Source Total</b>		<b>\$115,152</b>	<b>\$7,500</b>

Fiscal Year	Program	Students	MMS Funds	Matching Funds
2003	PhD	3	\$45,032	\$12,000
	M.S.	5	\$79,448	\$7,500
	Undergrad	1	\$1,349	\$0
	<b>Source Total</b>		<b>\$125,829</b>	<b>\$19,500</b>
2004	PhD	4	\$55,365	\$15,000
	M.S.	2	\$34,715	\$0
	Undergrad	0	\$0	\$0
	<b>Source Total</b>		<b>\$90,080</b>	<b>\$15,000</b>
2005	PhD	2	\$30,942	\$0
	M.S.	2	\$6,385	\$0
	Undergrad	1	\$1,398	\$0
	<b>Source Total</b>		<b>\$38,725</b>	<b>\$0</b>
2006	PhD	2	\$21,132	\$6,667
	M.S.	1	\$0	\$0
	Undergrad	2	\$0	\$0
	<b>Source Total</b>		<b>\$21,132</b>	<b>\$6,667</b>
2007	PhD	0	\$0	\$0
	M.S.	1	\$82,635	\$0
	Undergrad	0	\$0	\$0
	<b>Source Total</b>		<b>\$82,635</b>	<b>\$0</b>
2008	PhD	0	\$0	\$0
	M.S.	2	\$124,086	\$27,423
	Undergrad	0	\$0	\$0
	<b>Source Total</b>		<b>\$124,086</b>	<b>\$27,423</b>
2009	PhD	0	\$0	\$0
	M.S.	0	\$0	\$0
	Undergrad	0	\$0	\$0
	<b>Source Total</b>		<b>\$0</b>	<b>\$0</b>
2010	PhD	1	\$66,332	\$17,288
	M.S.	3	\$97,740	\$82,114
	Undergrad	1	\$34,620	\$0
	<b>Source Total</b>		<b>\$198,692</b>	<b>\$99,402</b>

	MMS	Matching
<b>Totals to Date</b>	<b>\$1,498,415</b>	<b>\$517,048</b>

## Total CMI Funding

The total MMS funding committed to CMI projects through calendar year 2010 is approximately \$16.7 million. All CMI-funded projects require a one-to-one match with non-federal monies.

## Sources of Matching Funds

Matching for CMI-funded projects has come from a wide variety of sources. Identifying and verifying match remains a major administrative challenge in the development of CMI proposals. In general, match has been available to those investigators who expend the necessary extra effort to locate and secure the support. The following partial list of fund matching participants demonstrates the breadth of support for CMI-funded programs:

Afognak Native Corporation	Dept. of Fisheries and Oceans Canada	UAF Institute of Arctic Biology
Alaska Beluga Whale Committee	Exxon Valdez Oil Spill Trustee Council	UAF Institute of Marine Science
Alaska Dept. of Environmental Conservation (ADEC)	Frontier Geosciences, Inc.	UAF International Arctic Research Center (IARC)
Alaska Dept of Fish and Game (ADF&G)	Golden Plover Guiding Co.	UAF School of Agriculture & Land Resources Management
ADF&G – Kachemak Bay Research Reserve	Japanese Marine Science and Technology Center (JAMSTEC)	UAF School of Fisheries and Ocean Sciences
Alaska Dept of Transportation and Public Facilities	Kodiak Island Borough	UAF School of Management
Alaska Science and Technology Foundation	Littoral Ecological & Environmental Services	UAF School of Mineral Engineering
Alyeska Pipeline Service Company	North Slope Borough	University of Alaska Museum
Ben A. Thomas Logging Camp	Oil Spill Recovery Institute	University of Alaska Natural Resources Fund
BP Amoco	Phillips Alaska, Inc.	University of Alaska Southeast
BP Exploration (Alaska) Inc.	Pollock Conservation Cooperative Research Center	University of California, Los Angeles
Canadian Wildlife Service	Prince William Sound Aquaculture Corporation	University of Northern Iowa
CODAR Ocean Sensors	Simon Fraser University	University of Texas
Cominco Alaska, Inc.	University of Alaska Anchorage	Wadati Fund
ConocoPhillips Alaska, Inc.	University of Alaska Fairbanks	Water Research Center
Cook Inlet Regional Citizens Advisory Council	UAF College of Science, Engineering & Mathematics	Woods Hole Oceanographic Institution
Cook Inlet Spill Prevention & Response, Inc.	UAF Frontier Research System for Global Change, IARC	



## CMI Publications

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### **The Department of the Interior Mission**

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering sound use of our land and water resources; protecting our fish, wildlife, and biological diversity; preserving the environmental and cultural values of our national parks and historical places; and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people by encouraging stewardship and citizen participation in their care. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.