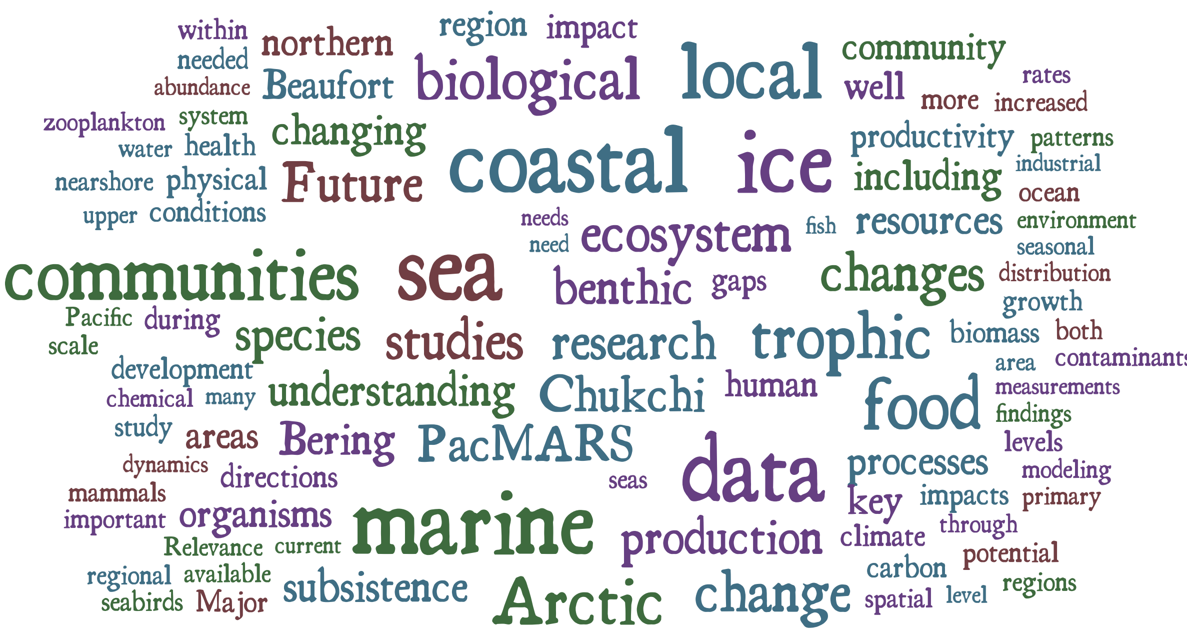
Pacific Marine Arctic Regional Synthesis (PacMARS)

Final Report



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EXECUTIVE SUMMARY

The Pacific Marine Arctic Regional Synthesis (PacMARS) is a research synthesis effort funded by Shell Exploration & Production Company and ConocoPhillips, and administered and managed by the North Pacific Marine Research Institute through the North Pacific Research Board with oversight from the U.S. National Science Foundation Division of Polar Programs. The goal of the **Pac**ific **M**arine **A**rctic **R**egional **S**ynthesis (**PacMARS**) effort is to facilitate new and cross-disciplinary synergies in our understanding of the marine ecosystem of the greater Bering Strait region, including the northern Bering, Chukchi and Beaufort seas. The specific objectives of the PacMARS research team and collaborators are as follows: (1) identify and synthesize existing data sets that are critical for evaluating the current state of knowledge of this marine ecosystem, including human dimensions, and (2) define the high-priority, overarching scientific themes and research needs for the next decade or more of marine ecosystem studies in the Pacific Arctic Region.

Seasonal sea ice continues to decline in the Arctic, with a record minimum observed in 2012. Offshore oil and gas exploration is anticipated in US waters and ship traffic is increasing through Bering Strait. These changes portend a different future for commercial activity, particularly if the Northern Sea Route along the north coast of Russia becomes a practical and cost-effective shipping route between Asia and Europe. The Northwest Passage through the Canadian Arctic has also become ice-free several times in recent summers, a significant change. All of the Arctic countries, including Russia, the United States, Canada, Denmark (Greenland) and Norway are exploring the limits of their arctic continental shelves to advance claims under the Law of the Sea Treaty.

Within this context of major environmental and socio-economic changes, wildlife populations and human communities are adjusting to shifts in seasonal sea ice coverage and climatic warming that has been much more obvious in the Arctic than at lower latitudes. Timing, availability, and accessibility of the subsistence harvests of marine resources by coastal residents of the Arctic are changing as stocks are altered in abundance and distribution. Productivity is also observed and forecast to change as sea ice declines and penetration of sunlight into open water increases. It is now clear that many organisms, from plankton to top predators are changing their distribution, migration and foraging patterns.

There are many important and scale-dependent reasons why the northern Bering, Chukchi and Beaufort seas – what can be termed the greater Bering Strait region - are of special concern. At the global scale (10,000 to 1,000 km) the Arctic Ocean has been transformed seasonally within the past few decades into an increasingly ice-free marine system where multi-year sea ice is now rare. The PacMARS study area is among the Earth's most prominent arenas for observing climate change and feedback regulation (e.g., impacts on ice cover/albedo and CO_2 sequestration). The through-flow of extensive freshwater runoff and nutrient-rich Pacific waters into the PacMARS study area affects circulation, stratification, productivity and ice cover in the North American basins of the Arctic Ocean and beyond. As an 'inflow shelf' communicating with the remainder of the world ocean, the northern Bering and Chukchi Sea shelves are sites of enhanced primary productivity and major biogeochemical transformations in elemental stoichiometry (e.g., N/P ratios in inorganic nutrients in response to denitrification) and carbonate saturation state (reflecting differences in carbonate buffering capacity among melting sea ice, runoff, and seawater). The entire PacMARS study area is a major migration pathway and rich habitat for globally significant populations of marine mammals and seabirds that annually migrate from as far away as the subtropical latitudes and even the South Hemisphere, respectively, to the Arctic to forage for abundant food resources. Within the Arctic, the Chukchi Sea, which together with the Bering Sea extends over the largest continental shelf in U.S. waters, has experienced the most spatially extensive loss of summer sea

ice of any of the Arctic marginal seas. On a wider scale, given the scope and speed of physical changes, it is not surprising that attention is now being focused on the inevitable biogeochemical and ecological consequences for the Arctic ecosystems and human society.

At the regional scale (1,000 to 100 km) the PacMARS study area characteristically exhibits very large temporal and spatial variability, process bottlenecks and biological hotspots. As climate change progresses and ice (presumably) diminishes, "tipping-point" (i.e. threshold-based regime shifts) phenomena are likely to be observed as one set of current predictable processes (e.g., sea ice retreat, phytoplankton bloom phenology, etc.) will be replaced by a new and different set of system component processes. For example, changes in coastal polynya dynamics and extent in both the Bering and Chukchi regions will impact the modification of regional water masses, such as cold pool renewal and Pacific Winter Water formation, with attendant effects on biogeochemical processes in the near- and far-field. It is at this scale that issues involving economic exploitation/development and environmental regulation will occur, and governance and sovereignty issues arise. It is noteworthy that oil and gas exploration and potential production efforts place an urgent timescale for ecosystem understanding prior to potential disturbances.

At the local scale (<100 km) challenges arise concerning the sustainability and welfare of local communities, especially those with economic and social dependence on subsistence harvesting from the marine environment. This is the scale that community residents know best, but it is a scale that is imperfectly evaluated by scientific studies that are seeking to promote ecosystem understanding that can be generalized to the biome level. For deeper understanding at this scale, the PacMARS team recognizes the importance of two-way exchange with local residents who are predominantly Alaskan Native, both with regards to their needs and specific concerns, and also to the wealth of knowledge available from local sources at appropriate spatial scales. Productive exchange has great potential for useful advances in ethnographic and natural science research, local scale understanding of the biome, and the development of effective co-monitoring and co-management of resources.

Involvement of the arctic residents in the data-gathering process of PacMARS has had strong, two-way benefits: (1) community members become more aware of the research activities taking place in their region, (2) researchers get firsthand exposure to the questions and concerns arising from the local perspective of understanding the ecosystem and they benefit from a more holistic view of the future research needs in the region, and (3) direct involvement of arctic residents leads to potential insights from Traditional Ecological Knowledge (TEK). As part of the PacMARS effort, community contributions to the study were documented during PacMARS community meetings on St. Lawrence Island (Gambell and Savoonga), and "hub community meetings" in Barrow, Kotzebue and Nome, Alaska, with tribal council representation drawn from several surrounding smaller coastal villages.

It should be noted that the original direction of the PacMARS synthesis was to evaluate existing data on physical forcing impacts to lower trophic organisms, with the upper trophic level component undertaken simultaneously through the Synthesis of Arctic Research (SOAR) effort. Funding for SOAR from the U.S. Bureau of Ocean Energy Management (BOEM) is coordinated with the National Oceanic and Atmospheric Administration (NOAA). A major goal has been to develop manuscripts focusing on upper trophic level populations in relation to physical forcing and lower trophic level connectivity. The PacMARS project effort, by comparison included physical, chemical and biological oceanographers, with one social scientist working in coordination with our original plan for local community "hub meetings" for coastal community input. As such, the PacMARS project in concert with products from the SOAR effort, is a first phase of a multi-dimensional, multi-agency process necessary to develop a coordinated, system level, natural and social science understanding of the changing Pacific Arctic region. We consolidated both published and unpublished data into synthesis products, including development of a composite document of available data sets and submission of summary data products to a PacMARS data archive coordinated by the Earth Observing Laboratory (EOL) at the National Center for Atmospheric Research (NCAR).

1. Report Format

The PacMARS report includes a background section for the major research topics relevant to the original objectives of the project, research themes, major findings, data gaps, and relevance of topics to local communities. We developed questions for future directions associated with the six core themes, and present a conceptual model of the Chukchi and Beaufort Sea marine system to guide future research program development. The format of the report is as followings: Chapter A provides an introduction to the PacMARS project, background on environmental and social topics, and outline of the initial research themes for the project. Chapter B summarizes the methodology used for the synthesis effort. Chapter C provides results and discussion of the PacMARS project data assimilation and findings. A notable product of the PacMARS project is Appendix G1 (the PacMARS Data Source Table), a comprehensive and annotated commentary on the perceived value of prior research in the Pacific Arctic region to our synthesis effort and the prospects for identifying insightful research questions for future consideration. Chapter D identifies the three emerging broad research themes and associated questions developed during the course of the PacMARS project. We then selected six core themes to aid in a discussion of future research program development and to identify methodological issues and approaches, data and/or knowledge gaps, and future research directions. This chapter also includes a conceptual model of the Pacific Arctic system and includes recommendations for a future research program.

In the course of the project, we identified six research foci that served as initial organizing principles for the PacMARS synthesis effort:

1. Sea Ice Cover (relationships with primary production, currents, and winds)
2. Phenology of Biological Production Cycles in Relation to Physical Environment
3. Pelagic-Benthic Coupling in Relation to Physical-Chemical Environment
4. Current State of Lower Trophic-Prey-Base and Higher Trophic Feeding Hot Spots
5. Chemical Contaminants in Water, Sediments and Biota
6. Subsistence Lifestyles in Times of Climate Change

We compiled multiple data sets and/or identified internet-based linkages to data sets while developing practical synthesis mechanisms associated with the 6 foci identified above. We utilized these data to develop programmatic themes and hypotheses for future research activities. Simultaneously, during the course of the study and meetings in local communities, the community members and representatives outlined marine issues of highest concern that focused on five major topics: (1) health, availability, and accessibility of marine mammals, fish, and seabirds, (2) fishing, hunting and food security, 3) oil extraction and mining, 4) shipping and ship traffic, and 5) sea ice, hydrography, and contaminants. We highlight the results of these community discussions in the report as well as provide a summary of the hub meetings on the PacMARS website (http://pacmars.cbl.umces.edu), also available as Appendix G8. Finally, the location of upper trophic level organisms is directly dependent on physical forcing and lower trophic level populations, thus we also identify how natural and social science can synergistically be utilized for developing coordinated research with goals of a system-level understanding of the region that serves to inform local, regional and national decision-making.

The data assembled and other synthesis products have been transferred to EOL and are publicly accessible at the PacMARS project data archive site: http://pacmars.eol.ucar.edu. The development of a data inventory, the integration of new datasets, and synthesis of this information using Geographic Information System (GIS) tools facilitated our second objective, to develop forward-looking science planning objectives and to identify science needs for a potential integrated, multi-agency research and modeling effort in the northern Bering/Chukchi/Beaufort region that could be initiated in the near future in conjunction with commitments already made by the North Pacific Research Board. This final report outlines synthesis activities undertaken by the investigators funded under this project and presents resulting products, along with a summary of future research needs.

The following meetings were held during this project (available products on the PacMARS website http://pacmars.cbl.umces.edu in parentheses):

- Sept 2012 PacMARS PI meeting, Annapolis, MD (open report)
- Dec 2012 PacMARS data meeting with PIs and collaborators, Boulder, CO (open minutes)
- Jan 2013 PacMARS/SOAR open community meeting, Anchorage, AK (open report)
- Feb-Mar 2013 PacMARS "hub" local Alaskan community meetings: Savoonga, Gambell, Barrow, Kotzebue and Nome, Alaska (open report)
- Jan 2014 PacMARS PI meeting, Anchorage, AK
- Nov 2014 PacMARS PI meeting, Center for Sustainable Forestry (Pack Forest), Eatonville, WA

In addition, there were several PacMARS PI Team conference calls, ad hoc meetings and other information exchange that served to keep status up to date and tracked milestones and the progress of synthesis activities

2. Recommended Broad-scale Research Themes and Proposed Directions for Specific System-level Studies in the Pacific Arctic

Through the course of the project we identified three broad-scale, overarching research themes and associated research topics that are pertinent to successfully launch a fully integrated ecosystem research program in the PacMARS region:

Theme 1: Impacts and connectivity of advective physical forcing and changing ice cover on ecosystem structure

Advection is a key forcing function for the Arctic marine system in general and the Pacific Arctic region in particular. Advection of water, ice and biological constituents through the Bering Strait creates the nutrient, plankton and organic carbon detrital "highway" that connects the Bering Sea to the Chukchi Sea and further to the Beaufort Sea and the Canada Basin. Inherently connected to advection, sea ice is a primary forcing factor in the PacMARS region and should be jointly considered in the context of advection. The Chukchi Sea is among the most vulnerable Arctic continental seas for ecosystem change, which has been mediated by the steep decadal decline in seasonal sea ice present in its waters; extensive proportions of shelf waters are now ice free in late summer of most years.

Theme 2: Phenology shifts as tipping points for ecosystem functionality

Phenology and extent of ice coverage are thought to regulate carbon partitioning between pelagic and benthic realms as well as impact life cycles of organisms that depend upon sea ice as habitat (e.g., walruses hauling out over the shallow continental shelf). Differences in physical and biological phenology across the Pacific Arctic region reflect system-level gradients, but spatial and temporal gaps in knowledge currently limit our understanding of ecosystem process and connectivity.

Theme 3: Dynamics within the nearshore zone

The nearshore zone (distance <20 nautical miles from coast) is the interface between human/biological communities and offshore ecosystem processes: it connects terrestrial biogeochemical systems to marine waters and oceanic carbon cycling. To improve our understanding of the Arctic estuarine system, we must enhance capacities for integrating and synthesizing spatio-temporally diverse data from observing platforms spanning the terrestrial, nearshore, and shelf domains.

The following discussion outlines the PacMARS team recommendations for future research within the six identified foci, including major findings, and knowledge/data gaps. In addition, hub meetings and interactions of PacMARS investigators with local residents over the past decades have shown that all themes considered during the PacMARS effort are in some way relevant for local residents and thus we have integrated a ‘relevance to local communities’ section into every theme listed below. Specific research questions that should be addressed within each theme are provided in Chapter D.

Recommended Research Direction #1: Evaluate the impacts and connectivity of a changing ice cover and physical forcing on lower trophic production and carbon cycling

Major findings: Sea ice cover has diminished dramatically over the last two decades, with later seasonal freeze up and earlier break-up, near extinction of multi-year ice in the PacMARS region, and longer ice-free periods in coastal zones. In recent years these changes in extent have been quantified regionally and on a pan-Arctic scale, from every perspective ranging from local observers to satellite sensors. Warmer summer sea surface temperatures also are observed in the northern Chukchi and fresher surface salinities in the Beaufort/Canada Basin since 2005 relative to previous years. Reduced sea ice cover also increases potential uptake of CO_2, with attendant ocean acidification and melted sea ice potentially reducing surface water alkalinity. In addition, several studies indicate that Arctic sea ice itself enhances CO_2 uptake, so a continuing reduction in sea ice by itself is likely to change the CO_2 source/sink relationship.

Knowledge/Data gaps: While PacMARS and SOAR data aggregations will enable clearer studies of ecosystem impacts of sea ice reduction on a regional scale, a comprehensive, temporally and spatially explicit carbon budget has yet to be constructed that details the sources and sinks for organic matter advected or produced locally for the Bering Strait region, Chukchi, or Beaufort seas. Uneven opportunities for data collection have made it difficult to evaluate temporal and spatial change in relation to biological production at the lower trophic levels within a systems perspective. Multiple data gaps exist, including: (1) the relationship among seasonal and interannual coverage of sea ice and primary production, (2) impacts of sea ice changes on organic carbon uptake in biota and potential sequestration to sinks, (3) impacts of sea ice cover on the balance of pelagic versus benthic carbon pathways, (4) lack of seasonal and spatial coverage for sentinel lower and upper trophic species, and (5) erosion, and wave regime studies in the nearshore coastal zone.

Relevance to Local Communities: Sea ice is of critical relevance for human communities living in the Arctic. While the typical marine science perspective places sea ice within the construct of marine systems, indigenous geographies regard icescapes as extensions of human settlement, marked by named places, travel routes, navigation markers, geophysical characteristics, and user memories. Shorefast ice provides a dynamic substrate extension to Arctic coastal communities during much of the year. Local knowledge often distinguishes many controls on animal behavior, abundance, and distribution in relation to ice conditions. Sea ice distributions are, in turn, greatly influenced by wind, with direction and intensity of wind having an impact on weather, snow, ice movement, and hunting opportunities. Among the expected changes on the part of community residents are accelerating coastal erosion and more frequent and severe storms, increased shipping traffic and planned development of petroleum resources and the potential noise and chemical disturbances associated with both. The appearance of new species with reduced sea ice cover was another concern of local observers, and is consistent with scientific observations. The importance of sea ice to coastal Arctic residents is underscored by the sustained prominence of this subject in numerous meetings, testimony, and community-based discussions. To be effective, future research programs must incorporate local community observations, participation, and purposeful outreach and education of project results.

Recommended Research Direction #2: Understand the phenology of biological production cycles in relation to the physical environment with a changing climate

Major findings: The phenology of biological production cycles is tied to the annual cycle of light in high-latitude ecosystems. This strong signal in light availability, combined with seasonal nutrient availability, typically results in a highly focused primary production peak in spring followed by a delayed peak in secondary production later in the season. Both sea ice algae and open water production exhibit a latitudinal gradient in intensity related initially to light, but controlled by a combination of light and nutrient availability. Life cycles of arctic animals are linked to the predictable timing of these peaks so that they can take full advantage of the extremely short growing season. The reproductive strategies of many zooplankton species have evolved to maximize their productivity during the growing season so that they can attain a stage of development that allows them to overwinter successfully. Many higher trophic level animals (i.e. bowhead whales and seabirds) time their migration patterns to these peaks in productivity as well, as PacMARS synthesis products have documented through aggregating multi-year efforts. The recent changes in seasonal ice coverage and the concomitant increase in light transmittance implies that production cycles may be changing with earlier open water and under-ice blooms that will lengthen the growing season and possibly increase the total productivity of the system.

Data gaps: PacMARS data aggregation efforts have visually documented the dominance of summer (and fall to some extent) measurements over the other seasons (Table D1). The largest seasonal gaps remain in winter for essentially any variable measured *in situ*. Retrospective assessments of interannual variability are limited by shifts in spatial focus of the studies over the decades. In addition, we have limited data on the cumulative effects of changing physical forcing on the timing, magnitude, and duration of biological and biogeochemical production cycles. Knowledge gaps in responses exist both in: (1) potential changes in colonization patterns and replacement of arctic endemics by subarctic populations/species, and (2) the capability of organisms to adapt and/or tolerate change. How these changes will affect the current production cycles of the arctic endemics, the potential colonization of Pacific expatriates, as well as the migration patterns and important use areas of seasonal migrants, is an open question.

Relevance to Local Communities: Community representatives during PacMARS hub meetings emphasized their *in situ* observations and concerns, specifically that changing seasonality of the marine ecosystem has the potential to displace or reduce in abundance the prey organisms of subsistence harvested upper trophic level predators (e.g., fish, seals, whales, ducks) as well as shifting the distributions of those subsistence species themselves. They expressed concerns that a shift in the timing of biological processes and the potential replacement of Arctic endemic species by subarctic populations/species affects the nutritional, cultural, and economic well-being of coastal human communities that rely on these marine resources. Changes in timing would directly affect the accessibility and availability of marine resources to communities. Additionally, a change in the body condition of marine organisms has the potential to directly affect human health as well as to exacerbate food security concerns. Range expansion by subarctic fish species may lead to the northward extension of commercial Arctic fisheries and introduce the potential for (time and space) conflicts with traditional subsistence activities, environmental disturbance (e.g. bottom trawling) and overfishing of target stocks.

Recommended Research Direction #3. Determine the role of pelagic-benthic coupling in relation to changing physical forcing and biogeochemical shifts

Major findings: On the Pacific Arctic regional scale, general spatial patterns of high and low algal and benthic biomass appear to have persisted over the past 3-4 decades, with larger variability in zooplankton densities. On the sub-regional scale, however, PacMARS and other regional synthesis efforts document region-specific variability and/or changes, or lack thereof. Pelagic algal biomass in the southern Chukchi Sea during summers after 2004 has remained consistently high in comparison with measurements from previous decades, which likely explains why key benthic depositional areas have been relatively unchanged in this region. Substantial increases in chlorophyll biomass just north of Bering Strait and along the northern shelf of the Chukchi Sea and substantial decreases in the western Chukchi/Herald Valley region during this later period (post-2004) potentially reduce carbon export to the benthos in the west, while increasing carbon export to the benthos in the northeast. In the early 2000s, pelagic-benthic coupling was very strong in the northern Chukchi Sea and western Beaufort Sea due to high primary productivity and low planktonic grazing pressure, especially during the spring ice algal/phytoplankton blooms. Our PacMARS analyses also indicate an increase in benthic biomass in the SE Chukchi Sea as a "chlorophyll and benthic biomass hotspot", implying an increased downstream deposition of more phytodetritus that is reaching somewhat further north. This is possibly the basis for the increased benthic standing stock in the NE Chukchi Sea since 2005 compared to pre-2005.

Data gaps: Improved process level understanding of the impact of changing climate forcing on the strength and direction of pelagic-benthic coupling is needed. Specifically, studies should focus on the partitioning of carbon flows between the water column and seafloor, and identify key species that will be affected by the potentially changing balance in organic carbon transfer from water column to benthos. Related to this partitioning, better understanding of mechanisms driving the development and persistence of pelagic and benthic areas of high biomass and productivity and of how those hotspots interplay with biogeochemical cycles.

Relevance to Local Communities: Carbon partitioning between the pelagic and benthic realms ultimately influences how stocks of pelagic- and benthic-feeding subsistence-harvested birds, fish and marine mammals may develop over time. The strength of pelagic-benthic coupling also determines the locations of dominant feeding sites and thereby indirectly controls access to preferred harvest species. Currently, benthic-feeding mammals (walruses and bearded seals in particular) are important subsistence food resources for coastal communities, and are dependent on concentrated and persistent benthic biomass as their food source. If walruses and bearded seals move further offshore or away from traditional feeding zones, these resources would become less available for coastal subsistence hunters. On the other hand, pelagic-dominated food webs could enhance abundance and/or availability of endemic or novel planktivorous or piscivorous predators for subsistence use. Timely knowledge of any regime shift would assist in adaptive responses.

Recommended Research Direction #4: Determine standing stocks, secondary production and food web structure of marine ecosystems in a local to regional context

Major findings: PacMARS data aggregations have documented biological patterns of composition, abundance and biomass of biological communities on a regional scale that are consistent with expected current patterns and other forcing functions. This is true for benthic fauna (>1mm), mesozooplankton, and fish. However, poor data coverage is a limitation in many nearshore areas. Synthesis results documented spatially and temporally persistent patches of high benthic biomass in contrast to large spatial and temporal variations in zooplankton standing stock. There is an overwhelming dominance of invertebrates in both diversity and standing stock over fishes. Copepod crustaceans dominate zooplankton diversity, abundance and biomass, whereas mollusks, polychaetes, crustaceans, and echinoderms dominate benthic diversity, abundance and/or biomass. Spatial distribution of marine mammals and seabirds has also improved considerably over the past decade, using visual observations and instrumental tracking methods, although understanding seasonal patterns remains a major limiting factor.

Data gaps: Gaps in biomass inventories still exist for: (1) biota missed by traditional sampling gear including krill (an important prey for bowhead whales) and deep-dwelling bivalves (an important prey for walrus), and (2) for small but likely important organisms in the food web (e.g., microzooplankton and meiobenthos). For most fauna or communities, however, data are lacking on population dynamics (i.e.

consumption, secondary production, growth and mortality). These data are required in order to model carbon flows, trophic efficiencies and understand time scales at which biomass is being produced. Such information will enable us to assess ecosystem resilience to changes or stressors. Understanding also is needed of the current role of different food source end members in Pacific Arctic food webs to evaluate the potential future roles of marine and terrestrial carbon sources under changing productivity, runoff and coastal erosion regimes. Future research planning should encourage the continuation and technological improvements to telemetry programs for marine mammals, fishes, and seabirds, as well as integration of passive acoustics more effectively into oceanographic field programs. Marine mammal vocalization data from passive acoustic arrays and animal distribution and behavioral data from satellite-linked tags help describe how, when, and why areas of preferential use are related to physical oceanographic features and phenomena. Common to this and most of the above themes is a lack of sufficient data at appropriate spatial and temporal scales to address all of the research questions identified.

Relevance to Local Communities: Biomass rich, productive and efficient food webs are intrinsic to maintaining the success of subsistence harvests. Due to the place-based nature of community harvests and limited geographic reach of traditional hunting, local-level assessments with sufficiently high resolution are as important as regional synoptic assessments. Shifting spatial distributions of subsistence species and/or changing composition of harvestable fauna will require adaptive operational strategies and have cultural implications to local communities.

Recommended Research Direction #5: Evaluate the chemical contaminant loads in sediments and biota for comparison to past studies and as a baseline for future monitoring of anthropogenic impacts of resource development

Major findings: A large data base for trace metals and polycyclic aromatic hydrocarbons (PAH) in surface sediments (with good QA/QC) shows essentially pristine sediments throughout the Chukchi and Beaufort seas. Some sediments within very small areas (<200 m around historic exploratory oil drilling sites, 6 of 35 studied to date) contain elevated concentrations of barium, chromium, copper, lead, mercury and polycyclic aromatic hydrocarbons (PAH) that can be linked to discharged drilling muds and cuttings. Sediment cores show no discernible metal or PAH contamination, even within the past 50-100 years, except for the immediate, but localized areas near past drilling sites. Time series data (1986-2006) with good QA/QC are available for metals and PAH in benthic organisms (amphipods and clams) from the coastal Beaufort Sea and show low concentrations with no significant temporal or spatial trends.

Data gaps Little or no data for chlorinated hydrocarbons (e.g., PCBs, pesticides) exist for sediments from the Chukchi and Beaufort seas. Limited data for metals and no data for PAH or other organic contaminants are available for water samples from the PacMARS area. Very few data are available to trace biomagnification of relevant chemicals (e.g., methylmercury, chlorinated hydrocarbons) in benthic food webs and in higher trophic levels. Data and models are required to determine how chemical contaminants in sediments and seawater move through the food chain, especially to upper trophic levels, including humans. A better understanding is needed of migration routes and important feeding regions for marine mammals, fishes, and seabirds and how these regions will change with anthropogenic impacts (e.g., climate change, industrial development, increased shipping).

Relevance to Local Communities: Community hub meetings and literature review confirms local concerns about contaminant levels in marine resources. These resulting food security and public health concerns are strong and pervasive in coastal communities throughout the PacMARS study area. Even where concerns were unlikely to be linked to significant actual hazards, the paucity of available data and ineffective communication of results to coastal communities facilitates speculation at the community level. Future research programs that involve chemical contaminants should incorporate local community observations, participation, and effective/relevant outreach and education of project results. Effective/relevant outreach and education includes the need for agencies and other researchers to consider their research in the context of human health and food safety and to provide results that are understandable, relevant, and meaningful to coastal community stakeholders.

Recommended Research Direction #6: Determine the impact of changing environmental conditions and food web dynamics on subsistence lifestyles in times of climate change

Major findings: Local traditional knowledge is being increasingly appreciated in western scientific efforts and each step, even those here, provides some progress towards bridging gaps between cultures and approaches. The nearshore coastal zone is very important for the subsistence harvest of marine resources by coastal communities, and is a critical migration pathway for marine mammals and seabirds, yet it is understudied because it is inaccessible by deep-draft research vessels. Major gaps exist in the bio-geo-physical linkages in the inner coastal shelf regions of both the Chukchi and Beaufort seas, where local residents travel, hunt and fish. More studies are needed that further our understanding of the ecosystems of this riverine coastal domain and its connection to the interplay of forces from land and outer shelf regions. In addition, coastal communities engaged in traditional subsistence practices are the first to notice novel species, wildlife population status and trends, wildlife disease, first sightings of migrants, pollution events, and coastal erosion.

Data gaps: There have been impacts on food gathering practices in coastal communities throughout the study area. Practical information needed to better understand these impacts includes how local communities directly and effectively adapt to the changes in the regional ecosystem, and how changes in sea ice type, extent, and duration, as well as maritime ship noise and traffic, contaminants, and increased commercial fishing pressure will affect the distribution, migration paths and health of marine animals used for subsistence. Additionally, it is unclear how the potentially negative environmental impacts described above will affect the accessibility and availability of marine resources essential to coastal communities for human consumption. More information is required on disease vectors affecting marine resources utilized by coastal communities and related human food security and public health issues. Other concerns include the impacts of offshore resource extraction including oil drilling as well as offshore, nearshore, and onshore mining activities; impacts of warmer seawater and air temperatures on sea ice and coastal erosion, as well as the erosion/integrity of critical infrastructure (i.e. roads, buildings, ice cellars); changes in ocean current patterns and ocean fronts, and wave regimes; and the need for education and research on effective exchange and integration of knowledge and results between the research science community and local residents.

Relevance to Local Communities: Throughout the PacMARS study areas, access to key species essential for coastal subsistence harvests has become more challenging. Increased distance and related fuel costs, safety in traveling and overcoming dynamic sea ice conditions are challenges for current-day food gathering. The changing ecosystem has led to increased risks, decreased accessibility to hunted foods, and less economic stability, as well as human health, and food security concerns in communities from the northern Bering Sea to the Beaufort Sea. Additional threats include commercial ship collisions with subsistence hunters in small boats and marine mammals, pollution events, invasive species, sub-arctic species range extensions, the introduction of novel diseases, and coastal erosion that impacts accessibility and community sustainability.

3. Methodological Needs for Future Research Activities

The research gaps and recommended future directions summarized in the previous section require a wide array of approaches, methods, and tools that we do not fully catalog here, although some are mentioned in Chapter D and Table D2. Because much Arctic ecosystem research currently is conducted under the broad framework of understanding the ecosystem in the context of climate change, we stress the roles of long-term monitoring and synthetic analyses of time series data including past data collections where available. Also, we stress the need for, and usefulness of, integrating interdisciplinary results into (predictive) modeling of changing ocean conditions to evaluate responses by marine biota, human life styles and industrial activities. Finally, a robust data management strategy is needed to guide data collection, processing and archival activities for each of the research directions. The following section outlines methodological objectives, associated major advances and infrastructure, and data gaps. Specific methodological needs associated with each methodological objective to facilitate PacMARS future research activities are provided in Chapter D.

Methodological Need 1: Long-term (multi-decadal) monitoring of the environment at multiple locations in the Pacific Arctic, and

Methodological Need 2: Time series retrospective analyses and synthesis studies

Major advances/infrastructure: There are few multi-decadal time-series data sets available from Arctic regions. Physical oceanographic moorings are deployed in the northern Bering Sea, Bering Strait, NE Chukchi Sea, in Barrow Canyon, and in the western and eastern Beaufort Sea. The Distributed Biological Observatory (DBO) is a developing time-series detection array composed of latitudinal transects and moorings being occupied by an international network for physical and biological measurements, but this program provides only limited benefits for process-oriented studies in the region. There are also no consistent time-series measurements in the nearshore coastal zone, a critical region for land-marine interactions and social connectivity.

Data gaps: There are critical needs for long-term studies that can lead to interpreting year-to-year variability in the coastal system, including a more extensive network of tidal gauges for sea level determinations and infrastructure that would facilitate resolution of long-period climate signals. There are only limited biochemical sensor capabilities currently available on moorings in the Pacific Arctic region. There are no equivalents in the Pacific Arctic to the LTER (Long-term Ecological Research) sites in the Antarctic or other marine and terrestrial systems where process studies are repeated seasonally and inter-annually. A lack of spatial and temporal coverage at the systems-level means that areas of high productivity dynamics, some producing persistent “hotspots” of productivity on an inter-annual basis, are poorly documented, and thus the key forcing factors are not evaluated at the appropriate scales. Other data needs include comprehensive daily/annual measurements of water column light profiles, biological processes and rates, studies of wintertime distributions and physiological states of phytoplankton and zooplankton as well as the processes controlling overwintering success and survival, and controlled laboratory studies of key organisms that provide data on growth and development as a function of temperature. These data all will facilitate appropriate parameterization of models, including determination of biogeochemical transfer processes to and from the sea ice or sea surface through the water column to the seafloor.

Methodological Need 3: Modeling and future scenarios

Major advances versus data gaps: Recent physical and biochemical modeling is facilitating evaluation of current and future impacts of changing atmospheric, water mass and current flow and biochemical processes in the Pacific Arctic. However, only a few modeling efforts couple trophic level biological responses to standing stock network analyses. We conclude that there is a need for fully coupled biophysical models at process scales linking physical parameters and trophic dynamics to ecosystem-level responses.

Methodological Need 4: Development and Implementation of a Comprehensive Data Management Strategy

We also point out that for any of the recommended research to be successful, it is important to develop and implement a robust data management strategy to help guide the data collection, processing and archival activities implied in each of the research directions outlined above. Consideration of a project data policy and data management support strategy that ensures continuity and consistency in data formats, collection protocols, long-term stewardship and access to the rich data legacy coming from these research activities is essential. The PacMARS PI Team spent extensive time gathering disparate data, unifying the data formats and building synthesis datasets (Appendix G4) that were key to providing the comprehensive analysis described in the full report. A similar effort will be required in the future. The research community can make that job much easier and more efficient if attention is paid to data management best practices in advance of any major data collection effort. This includes development of a detailed and accurate metadata profile for each dataset and the provision of clear documentation that accurate data collection and processing procedures.

4. Conceptual Model and Organizing Principles for an Interdisciplinary Research Effort

We developed a conceptual model for the nearshore and offshore regions of the Chukchi and Beaufort Seas to compare and contrast similar and more distinctive processes that can be used as an ecosystem starting point for evaluation (Figure D1). Processes relating to advection of water, heat and sea ice cover and loss and biological findings organize the conceptual model, and are likely important driving forces for future studies in this region**.** The conceptual model represents parts of the Pacific Arctic shelves as distinct areas, where varying inflow and advective characteristics have an influence upon, and interact in, a bi-directional manner with adjoining slopes, the nearshore region, and/or lagoons.

Based on our summary of the known gaps, we propose an interdisciplinary research program that will evolve around three core topics, listed here without priority:

(1) Impacts and connectivity of advective physical forcing and changing ice cover on ecosystem structure
(2) Phenology shifts as tipping points for ecosystem functionality
(3) Dynamics within the nearshore zone

Inherent to each topic is a need for geographical and disciplinary connectivity. The two broad-scale themes: advection and phenology, could be summarized within two directions of study: (1) how advection in the Pacific Arctic is driving regional gradients between the Bering Strait, southern and northern Chukchi Sea, and Beaufort Sea, in both nearshore and shelf areas; and (2) how sea ice conditions set up the phenology of the biological system and what influences those sea ice conditions have on overall pelagic and benthic productivity.

The research directions should be addressed through retrospective, field, and modeling efforts over various time and space scales to develop a systems understanding of the potential changes in the northern Bering, Chukchi, and Beaufort seas ecosystems. Rate process studies are typically not undertaken outside of narrow seasonal opportunities, but are vital to understanding how the ecosystem functions and how it will respond to change. Seasonal coverage has been lacking in most respects for studying biological processes. Moorings and gliders provide increased observational capability for the physical and potentially, chemical measurements, but investigating biological growth rate processes, and many biological distributions, requires field observations and experiments. Understanding prey-predator relationships and trophic phasing over multiple time and space scales should be a focus of field efforts, and require temporal population studies of key trophic organisms. The potential impact of ocean acidification and contaminant burdens are of key interest to both local residents and national policy planning efforts.

Based on the PacMARS findings of temporal and spatial mismatch of legacy data, we recommend that, whenever possible, time-series studies that include a composite of moorings, gliders, satellites and field process studies be set up with consistent and standardized methodologies. In addition, building field programs in light of retrospective findings and consistent with biogeochemical model budgets will enhance development of a coherent research program and associated modeling activities. Ecosystem network analyses are recommended as tools for integrating the various disciplines and scales of data collected during the PacMARS project. For over two decades such a study has been underway at the LTER site on the west Antarctic Peninsula, and a similar, comparative, long-term, time-series program is needed for the western Arctic marine ecosystems.

Coastal communities need to be encouraged to assist in specific socio-environmental studies that address their current concerns with respect to the quality of marine subsistence foods, lifestyle, and resource allocations as commercial and industrial vessel traffic increases. Further development of community-based and researcher-community collaborative monitoring efforts are needed. Such efforts should also link communities to one another so as to allow sharing of knowledge. There is a need to integrate regional subsistence-based understanding of local food webs, including changes in predator-prey relationships experienced by local observers, to provide insight to field researchers and modelers alike.

5. Afterword and Acknowledgments

The PacMARS effort was inspired in part to document the current knowledge that is available from the wealth of prior study that has intensified over the past couple decades. It is clear that while a much more detailed ecosystem understanding of the northern Bering, Chukchi and Beaufort seas is within grasp, truly integrated knowledge of the ecosystem will require further study.

We end by first thanking the many prescient scientists who pioneered work on the Bering Strait regional ecosystem over the past half-century, which gave us a basis to initiate this synthetic review. We also thank the local residents of the region who shared their opinions and specialized, local knowledge, and the industry partners who financially supported the study. This report benefited from the constructive comments received from the PacMARS advisory committee that helped improve earlier interim versions. Finally we thank the staff of the North Pacific Research Board, particularly program manager Danielle Dickson, and participating staff of the Division of Polar Programs of the National Science Foundation for their assistance in managing our efforts.

A. INTRODUCTION

The Pacific Marine Arctic Regional Synthesis (PacMARS) is a research synthesis effort funded by Shell Exploration and Production and ConocoPhillips, and administered and managed by North Pacific Marine Research Institute through the North Pacific Research Board with oversight from the National Science Foundation Division of Polar Programs. The **Pac**ific **M**arine **A**rctic **R**egional **S**ynthesis (**PacMARS**) effort was designed to facilitate new synergies in understanding of the marine ecosystem in the greater Bering Strait region, including the northern Bering, Chukchi and Beaufort seas. The overarching objectives of the PacMARS research team and collaborators were to: 1) identify and synthesize existing data sets that are critical for evaluating the current state of knowledge of this marine ecosystem, including human dimensions, and 2) define the high-priority, overarching scientific themes and research needs for the next decade or more of marine ecosystem studies in the Pacific Arctic Region (Fig. A1). This synthesis effort is contributing to NPRB's overall mission to promote understanding of North Pacific ecosystems in order to help enable effective management and sustainable use of marine resources, from subsistence use to fisheries to industrial exploration and development.

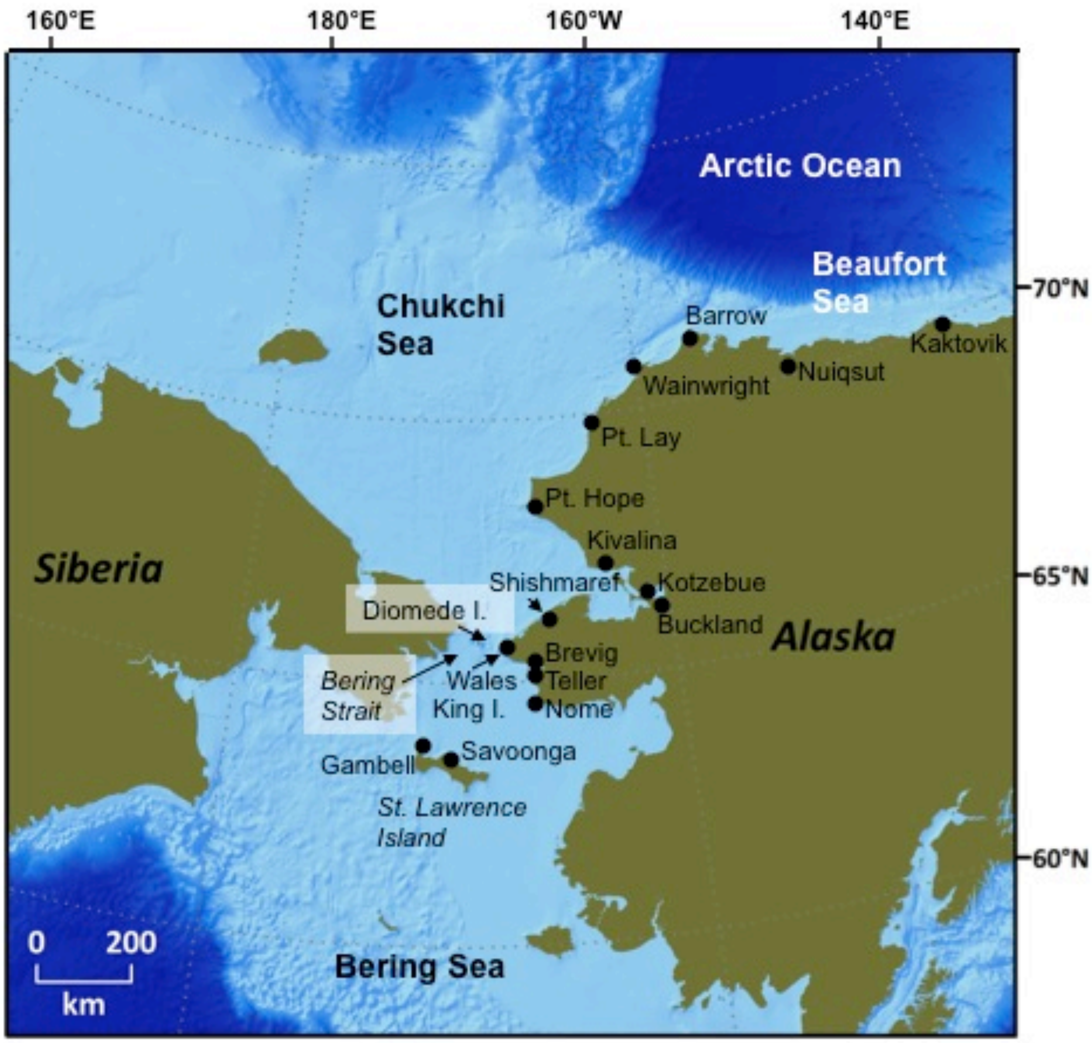


Figure A1. The region of the PacMARS synthesis effort in the Pacific Arctic.

During the course of the project we brought together multiple data sets and/or identified internet-based linkages to data sets while developing practical synthesis mechanisms. The data assembled and other synthesis products have been transferred to the National Center for Atmospheric Research (NCAR)'s Earth Observing Laboratory (EOL; http://arctic.eol.ucar.edu) and are publicly accessible. The development of a data inventory, the integration of new datasets, and synthesis of this information using Geographic Information System (GIS) tools facilitated our second objective, to develop forward-looking science planning objectives and to identify science needs for a potential integrated, multi-agency research and modeling effort in the northern Bering/Chukchi/Beaufort region that could be initiated in the near future in conjunction with commitments already made by the North Pacific Research Board. This final report outlines synthesis activities undertaken by the investigators funded under this project and presents resulting products, along with a summary of future research needs.

The PacMARS effort includes a broad-based investigator team (Table A1) of experienced investigators in biological, chemical, and physical oceanography in the region, as well as a cultural anthropologist, and a marine mammal specialist with the University of Alaska Fairbanks who has a responsibility as a Marine Extension Agent for extending the University's outreach in local communities of the Bering Strait region. We recognized that local stakeholders had knowledge and interests that could not be adequately represented by our efforts alone and sought input from local communities within the PacMARS study region. Specifically, we contacted tribal council authorities in the following villages to seek representation at village and "hub" scale meetings: Kaktovik, Nuiqsut, Barrow, Wainwright, Point Lay, Point Hope, Kotzebue, Kivalina, Buckland, Brevig Mission, King Island, Shishmaref, Teller, Nome, Gambell, Savoonga, Wales, and Diomede (Fig. A1). Residents of Gambell and Savoonga, the two villages on St. Lawrence Island, self-identify predominantly as Siberian Yupik (plural *Yupiget*) – an Inuit language spoken on the Russian and Alaskan sides of the Bering Strait. The indigenous population of all other villages in the study area is predominantly Iñupiaq (plural *Iñupiat*); Iñupiaq language variants are spoken throughout the Bering Strait and Arctic coasts of Alaska, Arctic Canada, and Greenland. We also recognized that the scientific outlook of most of the investigator team is oriented towards understanding the PacMARS study area from an ecological and oceanographic perspective, and we sought assistance from specialists on seabirds and marine mammals for perspectives on higher trophic components of local food webs.

Table A1. The PacMARS Principal Investigator Team and Advisors.

Institution	**PI**	**Expertise**
University of Maryland Center for Environmental Science (UMCES)	Jacqueline Grebmeier and Lee Cooper	Benthic ecology, interdisciplinary project management, biogeochemistry, biological & chemical oceanography
Florida Institute of Technology (FIT)	John Trefry	Trace metals, contaminants, chemical oceanography
University of Alaska Fairbanks (UAF)	Bodil Bluhm, Steve Okkonen, Gay Sheffield, Sveta Yamin-Pasternak	Benthic ecology, biodiversity, physical oceanography, marine mammals, marine advisory program, cultural anthropology
National Center for Atmospheric Research (NCAR)	James Moore	Data management, GIS data services
University of Rhode Island (URI)	Robert Campbell	Zooplankton ecology, molecular approaches, biological oceanography
University of Texas at Austin (UT)	Kenneth Dunton	Food webs, stable isotopes, benthic ecology
Woods Hole Oceanographic Institution (WHOI)	Carin Ashjian	Zooplankton ecology and lifecycles, biological oceanography

The PacMARS group has a two person advisory team, specifically: Eddy Carmack, Fisheries and Oceans Canada, Institute of Oceans Sciences, Sidney, BC Canada; and Robert Ulanowicz, who is affiliated with both the Department of Biology, University of Florida, and the Chesapeake Biological Laboratory, UMCES. Approximately a dozen collaborators to the project helped to fill in disciplinary gaps: Philippe Amstislavski, Downstate School of Public Health of the State University of New York; Arny Blanchard, Russell Hopcroft, Brenda Norcross, Imme Rutzen, and Tom Weingartner, all from UAF; Rob Bochenek, AXIOM, Inc.; Karen Frey, Clark University; Chad Jay, US Geological Survey, Anchorage; Kathy Kuletz, US Fish and Wildlife Service, Anchorage; Molly McCammon, Alaska Ocean Observing System; Sue Moore, NOAA/ Fisheries Office of Science & Technology; John Nelson, University of Victoria, BC, Canada and Robert Pickart, Woods Hole Oceanographic Institute. We also had constructive input during the project tenure from the PacMARS Steering Committee.

We also recognize the contributions over the years of many others to understanding the northern Bering, Chukchi and Beaufort Seas, and acknowledge the wide base of knowledge that this synthesis is based upon. We note in this context the passing in 2013 of two pioneers of research in the extended PacMARS study area, John Goering and Robert “Ted” Cooney, who provided early recognition of the importance of nitrogen cycling pathways and zooplankton dynamics to the cycling of organic matter, respectively. As research interest in the Arctic expands in scope, sophistication, funding, and numbers of researchers attracted by the opportunities, it is worthwhile to remember that our current, much better focused understanding of ecosystems in the northern Bering, Chukchi and Beaufort Seas rests on the shoulders of many who took advantage of opportunities in decades past.

A1. Project Objectives

The objectives of the PacMARS effort were to:

1. Identify and link existing data sets, tabulate data archive sites and provide value-added annotated metadata for existing data sets that promote understanding of the marine ecosystem extending from north of St. Lawrence Island in the Bering Sea to the Chukchi and Beaufort seas, including traditional ecological knowledge where it could be readily transferred (**Data synthesis**).

2. Synthesize existing scientific and traditional knowledge of the marine ecosystem, with a focus on territorial waters of the United States and its adjoining Exclusive Economic Zone, but to also include input from beyond this region through international collaborations with Russian [e.g. Russian-American Long-term Census of the Arctic (RUSALCA)] and Canadian [e.g. Canada’s Three Oceans program (C3O)] scientists cooperating with our effort. Other internationally generated data within the Pacific Arctic Group (PAG) international framework were also included (**Data synthesis).**

3. Develop overarching scientific themes and research needs to facilitate the design of the next iteration of integrated marine ecosystem studies in the Pacific-influenced Arctic, including the appropriate temporal and spatial scales of data needed for ecosystem-level assessment. (**Research Needs**).

4. Emphasize system-wide, synoptic understanding, in addition to discipline-specific syntheses of the northern Bering, Chukchi and Beaufort ecosystems. Given time and resource limitations, we prioritized our efforts towards integrating across disciplines and we used geographical and habitat-scaled approaches to achieve linkages among bio-physical observations and human communities (**Research Needs**).

5. Undertake a social-ecological science synthesis of (1) major research initiatives, (2) emerging research approaches and methods, and (3) documented research needs and concerns. Each of these approaches was directed towards identifying current research directions and gaps in knowledge concerning the maritime societies living within the marine ecosystems of the Northern

Bering, Chukchi, and Beaufort Seas. Cumulatively, this contribution resulted in an interdisciplinary socio-ecological synopsis of these marine ecosystems **(Research Needs**).

A2. Research Themes

We identified 6 research themes as foci for the PacMARS synthesis effort at the core of our funded project, developed to align with potential future field research efforts. Below we also provide specific questions that have resonated over the synthesis effort as worthy priorities for future research that are associated with these themes.

<u>Theme 1: Ice cover – primary production relationships, currents, winds, bathymetry</u>

1a. Will warmer water temperatures and reduced ice cover result in an increase in primary production in Arctic seas, and if so, how will this affect the sequestration of carbon, ocean acidification and food web dynamics?

1b. What is the connectivity to local/regional biogeochemistry and physical oceanography for the Chukchi and Beaufort Sea food web?

<u>Theme 2: Phenology of biological production cycles in relation to physical environment</u>

2a. How will a changing climate affect the timing, magnitude, and duration of production cycles?

2b. Will changes likely result in successful colonization and replacement of arctic endemics by subarctic populations/species?

<u>Theme 3: Pelagic-benthic coupling in relation to physical-chemical environment</u>

3a. Will future climate conditions alter the strength of pelagic-benthic coupling and if so, in which direction?

3b. How will keystone species be affected?

<u>Theme 4: Current state of lower trophic prey-base and higher trophic feeding hot spots</u>

4a. How will migration routes and important feeding hotspots of marine mammals and seabirds change in response to changing climate conditions and increased industrial and commercial activity?

4b. What are the current relationships between biodiversity and productivity?

<u>Theme 5: Chemical Contaminants in Sediment and Biota</u>

6a. What are the concentrations of chemical contaminants in sediments and seawater and how do they move through the food chain?

6b. Are there any potential impacts of varying contaminant burdens in sediment and invertebrate prey on high trophic organisms, including humans?

<u>Theme 6: Subsistence lifestyles in times of climate change</u>

5a. How will the subsistence food gathering of Native Alaskans in coastal villages change from the northern Bering Sea to the Beaufort Sea as environmental changes occur?

5b. What information is needed by communities to effectively adapt to the changes in the regional ecosystem?

In the following section, basic background for the major themes of this report are provided, then methodologies undertaken within the synthesis, followed by a fuller description of the analytical results and synthesis products, and we summarize research gaps and needs for future studies. We recognize that this thematic approach is not all encompassing and we note for example that higher trophic portions of the food web are not treated comprehensively in this report because of the specialties of the funded investigators and that the coincident Bureau of Ocean Energy Management (BOEM)-funded Synthesis of Arctic Research (SOAR) project had a focus on upper trophic connection to variable ecosystem components (see next section and Appendix G2). In addition, the social science component was limited by funding of only one specialist within the PacMARS project. We have, however, attempted to tabulate most, if not all of the relevant natural and social science research programs that have been undertaken in the PacMARS study area in Appendix G1 (PacMARS Data Source Table, 43 pp), including summary synthesis statements provided by our upper trophic level collaborators. Note that in Appendix G1 we provide, as practical, annotated commentary on the perceived value of the overall prior research to our synthesis effort and the prospects for identifying insightful research questions for future consideration.

A3. Synthesis of Arctic Research (SOAR) and Upper Trophic Levels

A3.1 The SOAR project

The Synthesis of Arctic Research (SOAR) is a 5-year project (2012-2017) supported by BOEM and the National Oceanic and Atmospheric Administration (NOAA). SOAR is chartered to synthesize scientific information and local observations to improve understanding of the relationships among oceanographic conditions, benthic organisms, lower trophic prey species (forage fish and zooplankton), seabirds, and marine mammal distribution and behavior for the Pacific Arctic region. The SOAR effort builds on existing interdisciplinary work to develop detailed syntheses to inform management decision-makers and to guide future research studies. Both PacMARS and SOAR have synergistic interactions as both projects were undertaken during the first portion of the 5 yr SOAR project. A visualization of the synergies of these two coincident projects, with the core PacMARS and SOAR objectives differentiated by color-coding, is provided below (Fig. A2). We also have a table in Appendix G2 of manuscripts being prepared by the parallel SOAR project that focuses on upper trophic level syntheses.

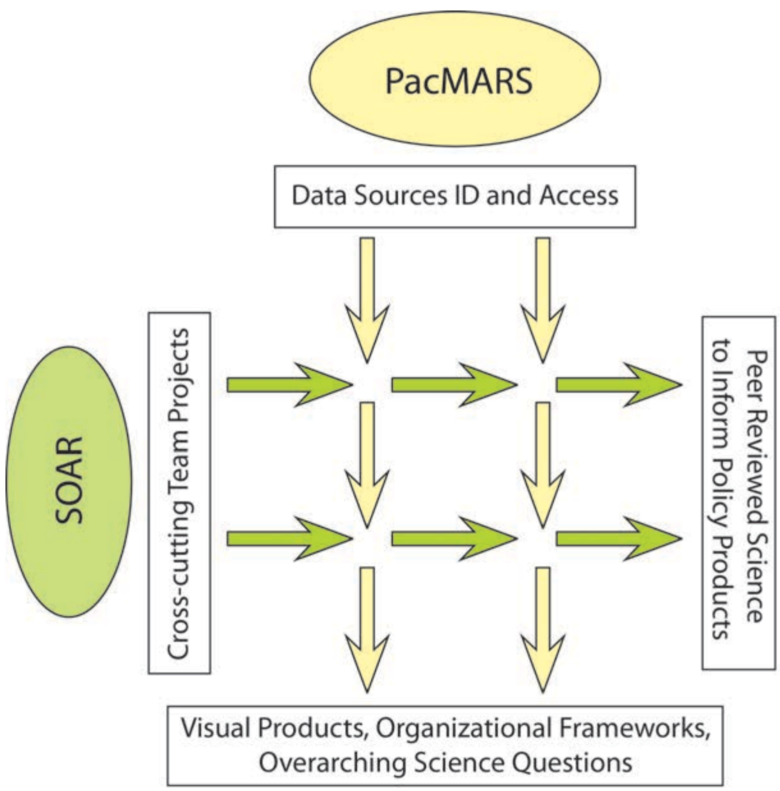


Figure A2. Schematic diagram outlining the synergistic activities of the PacMARS (Pacific Arctic Marine Synthesis) project and the SOAR (Synthesis of Arctic Research) projects. The core PacMARS objectives are identified by vertical yellow lines and the core SOAR objectives are identified by horizontal green lines.

Based on the synergistic objectives of PacMARS and SOAR, we jointly sponsored an open community workshop on 20 January 2013, just prior to the 2013 Alaska Marine Science Symposium in Anchorage, Alaska, to provide a prospective on underway and planned activities and to solicit input on potential priorities for future research initiatives in the region (Grebmeier and Cooper, eds., 2013). The meeting report is available at: http://pacmars.cbl.umces.edu/PacMARSSOAROpenScienceMeeting.html.

The combined PacMARS and SOAR projects have been supplemented by other independent scientific community efforts, including workshop discussions during the April 2013 Lowell Wakefield Fisheries Symposium ("Workshop: Toward a Conceptual Model for Arctic Shelf Ecosystems", http://seagrant.uaf.edu/conferences/2013/wakefield-arctic-ecosystems/info.php#arcticworkshop, a conceptual modeling workshop organized by the Office of Science and Technology Policy, Executive Office of the President (Dickson et al. 2014), and the National Research Council study on "The Arctic in the Anthropocene: Emerging Research Questions" (http://www.nap.edu/catalog.php?record_id=18726). In addition, the recently published Springer book entitled "Pacific Arctic Region: Status and Trends in a Rapidly Changing Environment" (Grebmeier and Maslowski, 2014 and chapters within) provides a synthesis of physical, chemical, biological data and modeling efforts in the Pacific Arctic region, with nearly 50% of the book having synthesis chapters covering physical processes (atmosphere, sea ice, and physical oceanography). Each of these synthesis chapters includes emerging questions for Arctic research in this region. These combined activities should, in principle, provide the scientific community and agency managers with a variety of options and information on research needs in the region.

A3.2 Upper trophic levels, SOAR and PacMARS

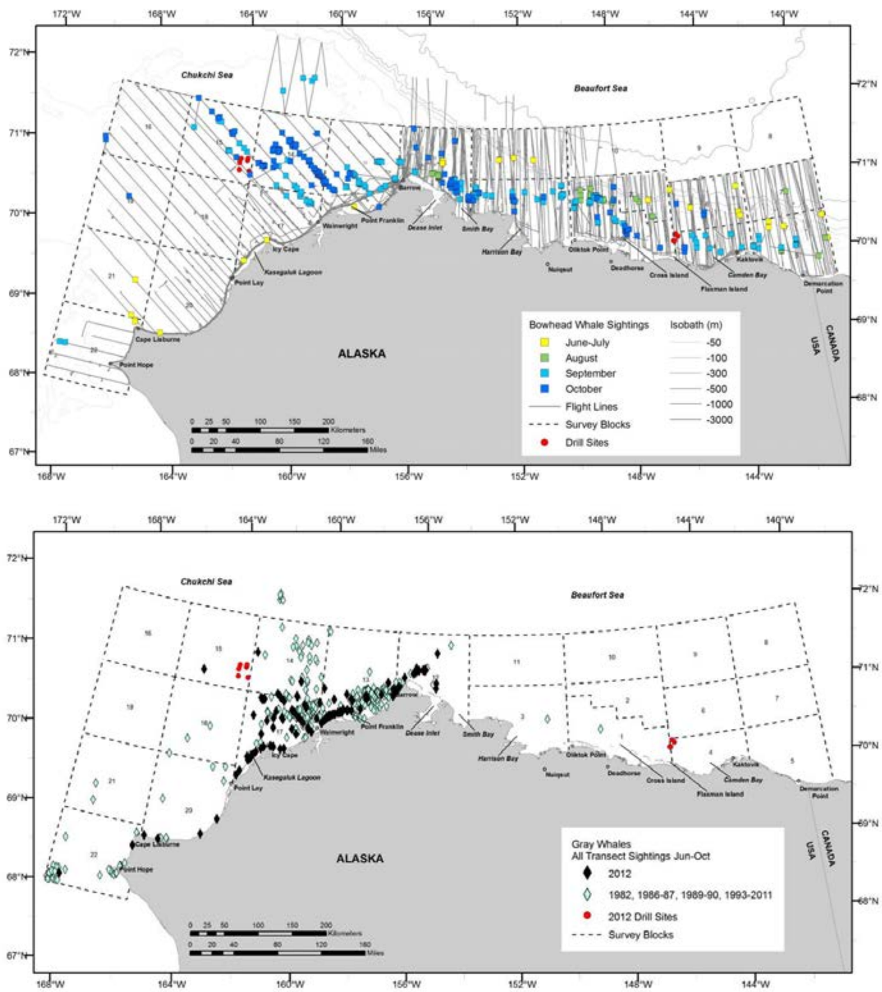
Upper Trophic Level synthesis has always been considered a focus of the SOAR effort, although some of the data are also included in PacMARS efforts. The following sub-sections A3.2.1 – A3.2.3 include abbreviated summaries of available data and data products from long-term studies on marine mammals, seabirds and fish with data sets available at the federal, state and local level. We outline here the extent of their incorporation into SOAR-PacMARS synthesis activities (Appendix G2). These data are particularly being used for higher trophic level SOAR efforts and we discuss these linkages here, where appropriate to PacMARS. Further details for accessing these data are in the Appendix G1 data source table.

A3.2.1 Marine mammals

The population dynamics, ecology and health of marine mammals has been a key research focus in Alaska since the 1970s, in part driven by concerns of coastal Inupiaq communities who rely on these species for food and cultural subsistence. In addition to studies conducted by Federal agencies (NOAA, BOEM, the US Geological Service (USGS), the US Fish and Wildlife Service (USFWS), the Alaska Department of Fish and Game (ADF&G) and the North Slope Borough/Department of Wildlife (NSB/DW) have been instrumental in establishing and maintaining long-term research programs. Synthesis papers using topic-appropriate data from all these sources are anticipated in the upcoming special issue of *Progress in Oceanography*, the central product of phase one of the Synthesis of Arctic Research (SOAR; see: http://www.arctic.noaa.gov/soar/; Appendix G2). In addition, integrative aspects of research on marine mammals, birds and fish are presented in Moore et al. (2014), emphasizing the role of upper trophic species as iconic sentinels of ecosystem variability and reorganization. Below are brief highlights of key marine mammal projects in the PacMARS region:

1. The Aerial Surveys of Arctic Marine Mammals (ASAMM) project is a continuation of the Bowhead Whale Aerial Survey Project (BWASP) and Chukchi Offshore Monitoring in Drilling Area (COMIDA) marine mammal aerial survey project. The goal of these studies is to document the distribution and relative abundance of bowhead, gray, right, and fin whales, belugas, and other marine mammals in areas of potential oil and natural gas exploration, development, and production activities in the Alaskan Beaufort and northeastern Chukchi Sea. Data from the ASAMM surveys are used to relate variation in marine mammal distribution or abundance to other variables, such as physical oceanographic conditions, indices of potential prey density, and anthropogenic activities, if information on these variables is available (1979-201). Funding is provided by BOEM and the work is currently conducted by NOAA.

Specific objectives for the survey project include: describing the annual migration of bowhead whales across the Alaskan Arctic, significant inter-year differences, and long-term trends in the spatial distribution and timing (duration and start date) of the migration. The project documents relative abundance, spatial and temporal distribution, and behavior (including calving/pupping, feeding, hauling out) of marine mammals (cetaceans, ice seals, walruses, and polar bears) in the Alaskan Arctic. The joint project provides near real-time data and maps to BOEM and NMFS on marine mammals in the Alaskan Arctic, with specific interest in endangered species, such as bowhead whales. Finally, a key effort is to provide an objective, area-wide context for understanding marine mammal ecology in the Alaskan Arctic, to help inform management decisions and interpret results of other small-scale studies. An example of the survey results from 2012 indicate the seasonal location of bowhead and gray whales in the NE Chukchi Sea region (Fig. A3). Further details on the ASAMM project can be found in Appendix G1.3a.



a.

b.

Figure A3. A. Aerial surveys of bowhead whale sightings plotted by month, with transect, search and circling effort, 2012. b. Gray whale sightings on transect in years with light sea ice cover: 1982, 1986-1987, 1989-1990, 1993-2011, and 2012. Includes all sightings on transect, from primary and secondary observers [from http://www.afsc.noaa.gov/nmml/PDF/COMIDA-2012-Report.pdf].

In addition to the long-term ASAMM program, since 2006 the NMML (National Marine Mammal Laboratory/NOAA) has received funding from BOEM for various marine mammal-oceanographic integrative research activities, including the BOWFEST (Bowhead Whale Feeding Ecology Study) and CHAOZ (Chukchi Acoustic, Oceanographic, and Zooplankton Study) programs, which are now combined in a cruise-based program called ArcWEST (Arctic Whale Ecology Study). All these research programs focus on marine mammal distribution, behavior and especially feeding ecology (see Appendix G1.6-Multidisciplinary Programs, for further details). Similarly, NOAA conducts semi-annual research cruises that sample the full Chukchi Sea during the RUSALCA (Russian-American Long-term Census of the Arctic) program. Visual observations of marine mammals are made along the RUSALCA cruise track, in addition to year-long passive acoustic sampling via moored recorders (on the US side only), similar to those used in the BOWFEST, CHAOZ and ArcWEST programs noted above.

2. The Chukchi Sea Environmental Studies Program (CSESP) is a multi-year, multi-discipline marine science research program in the northeastern Chukchi Sea, funded by a consortium of oil and gas companies, specifically ConocoPhillips Company, Shell Exploration and Production Company and Statoil USA E&P Company. The program began collecting information in 2008 on physical oceanography, ocean acidification, atmospheric conditions, sediments, benthic (epifauna and infauna), plankton ecology (zooplankton, phytoplankton, and primary production), fish, seabirds, marine mammals, and underwater acoustics. The SOAR Acoustics Ecology project includes data from this source, in combination with recordings support by Cornell University, Scripps Institution of Oceanography, NOAA/NMML and NSF/AON. Data collected during the CSESP program are available for use through the Alaska Ocean Observing System (http://www.aoos.org/industry-arctic-data/). For the PacMARS study area, these data are a rich resource, although the short duration of the PacMARS synthesis project has limited our capacity to fully assimilate the contributions made by the intense scale of the sampling in areas that may be impacted by oil and gas extraction. A recent volume of Continental Shelf Research, Volume 67 (2013) has multiple scientific articles covering the results from this program and is available on an open access basis at: http://www.sciencedirect.com/science/journal/02784343/67. Various data sets from this program are included in lower and upper trophic level manuscripts within the SOAR program (Appendix G2).

3. The Alaska Department of Fish and Game (ADF&G) conducts numerous long-term research programs, which often supplement and complement those undertaken by federal agencies and Alaska Native organizations. Currently research projects are underway on Steller sea lions, harbor seals, ice seals, walruses and whales, with most ADF&G current research on marine mammals in the Arctic funded by BOEM. The ADF&G also maintains long-term data on marine mammal diets, with some data dating back to the 1960s. The results of ADF&G research programs have substantially increased knowledge of the biology and ecology of Alaska's marine mammals, which has subsequently improved the understanding of how marine mammals interact with commercial fisheries. The program results provide important information to Alaska Natives for their subsistence use of marine mammals as well as to organizations concerned about the impacts of various human activities on marine mammals. The ADF&G marine mammal program works closely with the National Marine Fisheries Service and the U.S. Fish and Wildlife Service, the two federal agencies that assumed jurisdiction for marine mammal management in Alaska in 1972 with passage of the Marine Mammal Protection Act. In addition, the ADF&G works effectively with Alaska Native marine mammal organizations to promote co-management of marine mammals. The SOAR program anticipates two papers will be incorporated into the special issue of Progress in Oceanography, based in part on data from the bowhead-tracking project.

4. The North Slope Bureau (NSB)/(Department of Wildlife Management (DWM) facilitates sustainable harvests and monitors populations of fish and wildlife species through research, leadership, and advocacy from local to international levels. The DWM diversifies funding opportunities through the submission of grant proposals focusing on subsistence species and issues of the highest interest to North Slope residents. Species and research foci include arctic fox, Alaska beluga whales and tracking results, bowhead whales and tracking results, caribou, fish, health assessment of subsistence user resources, ice seals, migratory birds, NSG/Shell baseline studies program, oceanography and sea ice, polar bears, subsistence harvest documentation and walrus. Of these, the approximate 35-year data series on the bowhead whale ice-based census, and on bowhead body condition and diet, are two of particular note. A SOAR bowhead whale paper is specifically drawing on this data series (coupled with sea ice analysis) to investigate the variance of whale numbers, body condition and environmental variables.

5. The U.S. Geological Survey (USGS) seeks understanding of how losses of sea ice during summer in the Chukchi Sea will affect the walrus population. USGS developed a satellite radio-tag that can be deployed by crossbow to record when walruses are feeding or resting out of water. Data from these tags provide important information on walrus behaviors and habitat associations that will be critical for managing expansion of offshore resource development activities and for understanding the consequences of summer sea ice loss due to climate change. Walrus radio-tagging data are supporting a number of studies, including descriptions and publicly available GIS maps of walrus foraging areas in the Chukchi Sea (Fig. A4). In addition, USGS sponsored the creation of the Pacific Walrus International Database (PWID),

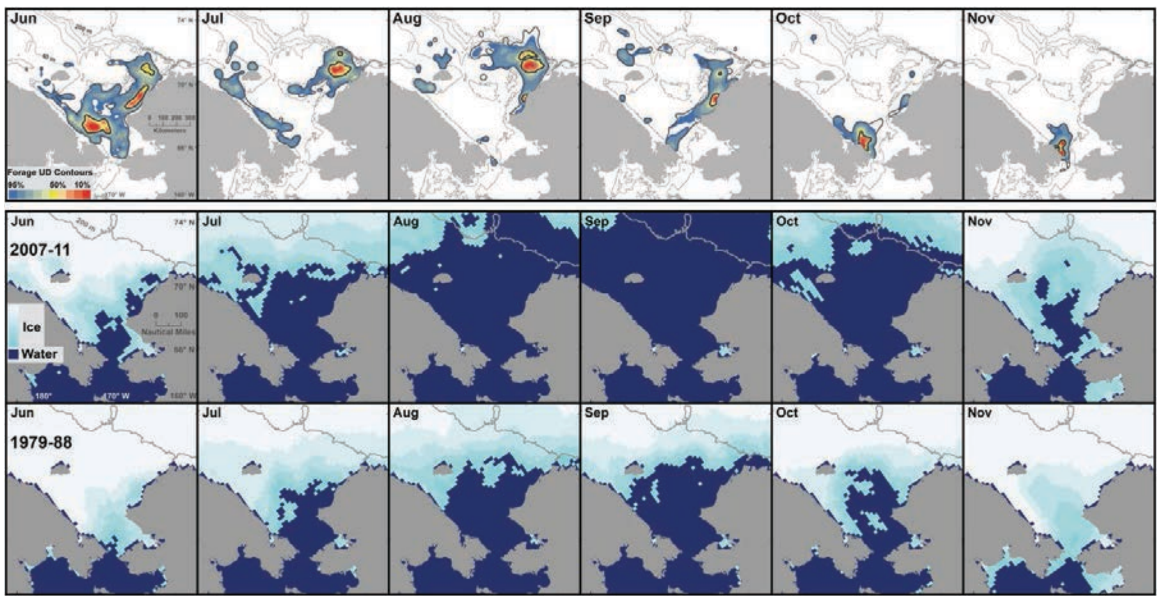


Figure A4. Top panel: Utilization distribution (UD) estimates of Pacific walrus (*Odobenus rosmarus divergens)* foraging (red to blue color ramp contours, 10-95% UDs) and occupancy (solid line contours, 50% and 95% UDs) in the Chukchi Sea, 2008–2011. Bottom panels: Average monthly sea ice extent during June–November in the Chukchi Sea 2007–2011 and 1979–1988. From Jay et al. (2012).

which is an archive of biological data collected in the Bering and Chukchi Seas by several participating organizations in the U.S. and Russia. The SOAR benthic hotspot paper is utilizing walrus data in a synthesis mode with other upper trophic level and oceanographic parameters.

6. The National Marine Mammal Laboratory (NMML)'s Ice Seal program: The Polar Ecosystems Program: Ice Seal Distribution Data <http://www.afsc.noaa.gov/nmml/polar/> states that "research projects" focus primarily on abundance, trends, distribution, and foraging behavior of harbor, bearded, ringed, spotted, and ribbon seals in Alaska. Substantial support for the Ice Seal program undertaken by NOAA comes from BOEM. The primary objectives of the program are to support management and assessment of population status under the Marine Mammal Protection Act, and to gain a better understanding of the factors responsible for the dynamics of populations and their roles in the ecosystem (metadata and shapefiles available)." Relevant citations include: Bearded seal (*Erignathus barbatus*;

Cammeron et al. 2010), Ringed seal (*Phoca hispida*; Kelly et al. 2010a,b), Ribbon seal (*Histriophoca fasciata*; Boveng et al. 2013) and Spotted seal (*Phoca largha*; Boveng et al. 2009).

A3.2.2 Seabirds

Alaska marine waters support nearly 87% of seabirds that breed in the U.S., with populations estimated at 50 million seabirds. The U.S. Fish and Wildlife Service (USFWS) is responsible for all migratory birds, including marine birds that move from onshore breeding colonies to pelagic waters during the non-breeding season. As part of the survey and monitoring of breeding seabirds, the Alaska Maritime National Wildlife Refuge (AMNWR) conducts surveys and supports a variety of studies throughout the state. Further information on UWFWS resource and data sites are available in Appendix G1.3b Seabirds. Below are some comprehensive seabird databases.

1. UWFWS Seabird colony database available through http://seabirds.net/seabirdinfonetwork.html. As an example of synthesis products from these data the seabird colony location and size has been combined with survey data to improve analyses on hotspots of seabird distribution **(**Fig. A5). Few long-term studies exist at seabird colonies in the Pacific Arctic, with the exception of two sites monitored by the Alaska Maritime National Wildlife Refuge – the Cape Lisburne colony (mainland Alaska on the eastern Chukchi Sea) and Bluff colony (mainland Alaska in the North Bering Sea, Norton Sound) (from Kuletz and Karnovsky 2012). Two species have been monitored at these sites since the late 1970s, the black-legged kittiwake and the common murre (*Uria aalge*). Between 1975 and 2009, kittiwake numbers have increased overall at Cape Lisburne, but their reproductive success has declined since 2004 (Dragoo et al. 2012), which may suggest immigration to the region by birds from elsewhere looking for a new place to nest. At the Bluff colony, both kittiwakes and murres have shown stable population trends, but their mean hatching dates have been earlier than the long-term (1975-2009) mean (Dragoo et al. 2012); the earlier hatch dates suggest an adaptation to earlier prey availability by both seabird species.

Because the two species of murres, the common murre and thick-billed murre (*U. lomvia*) are widespread and relatively abundant throughout the Arctic, they may serve as sentinels of the arctic marine ecosystem, and have been identified as key monitoring species by the Circumpolar Seabird Group of the Conservation of Arctic Flora and Fauna (CAFF; Petersen et al. 2008). In a pan-Arctic study of both murre species, data from 32 common and 21 thick-billed murre colonies were used to examine population trends and the potential influence of sea surface temperature (SST; Irons et al. 2008). The more arctic thick-billed murre colonies increased in size when SST warmed slightly, whereas the more temperate common murre colonies increased with moderate cooling, but both species had negative trends when SST changes were extreme, regardless of direction. These patterns showed synchronous fluctuations relative to SST, with changes in trends being synchronous within ocean basins and opposite between the two basins (Pacific and Atlantic). These population trends might reflect changes in the prey base, but this remains to be determined.

2. At-sea surveys. Alaska has a long, though sporadic, history of at-sea surveys for marine birds dating back to the 1970's OCSEAP surveys. Seabird surveys have continued in the Bering Sea and Arctic waters, particularly during 2007-2013 programs funded by NPRB and BOEM. The distribution and species composition of marine birds relative to physical and biological characteristics in the arctic are being examined in three components of the SOAR program: 1) nearshore benthic prey, 2) seasonal hotspots for marine birds and mammals, and 3) trophic productivity at Barrow Canyon. Seabird surveys available for these efforts include data from spring, summer and fall (Fig. A6), and will be used to improve our understanding of relationships among oceanographic conditions, lower trophic (benthic organisms, forage fish and zooplankton) and upper trophic (seabirds and marine mammal) in the Pacific Arctic. These data are being used in a SOAR synthesis manuscript.

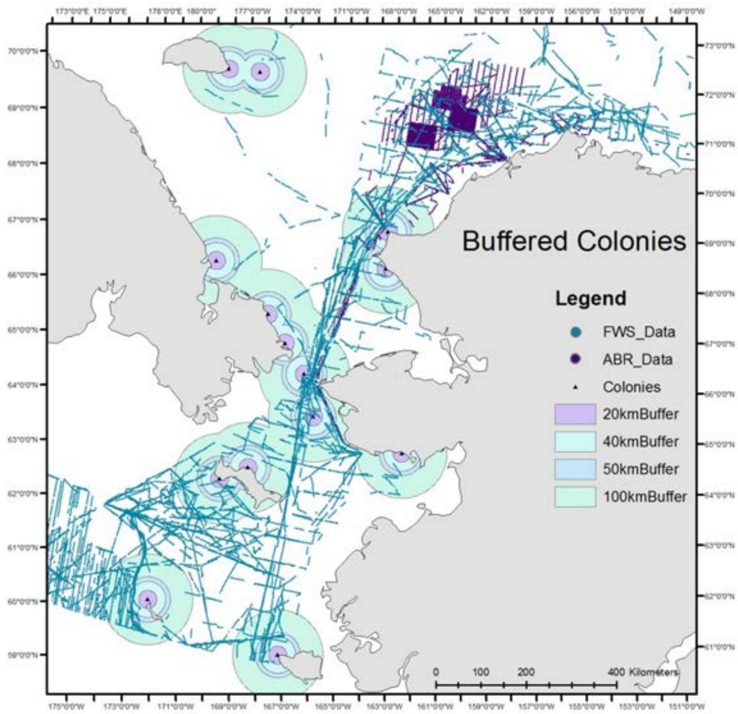
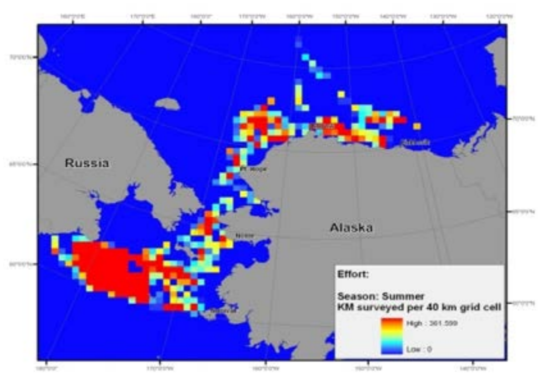
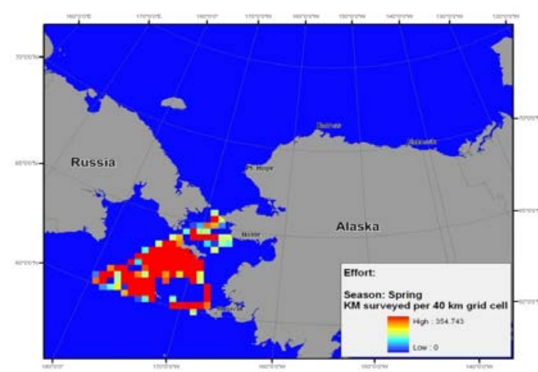


Figure A5. Location of seabird colonies in the PacMARS area, relative to at-sea survey transects used for SOAR analyses. Buffers indicate potential foraging ranges for various seabird species. Seabird data available from Kathy Kuletz, USFWS.



a.



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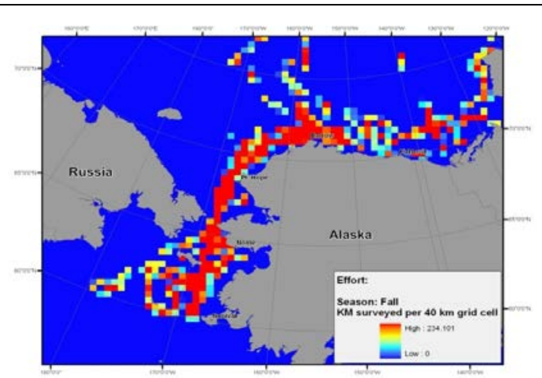


b.

Figure A6. Marine bird survey effort for the PacMARS area in spring (a.), summer (b.) and fall (c). Densities (birds/km^2) were calculated in 3-km segments and total number of segments combined in 40x40 km cells. Maps of survey effort by Brendan Hurley, as part of Synthesis of Arctic Research (SOAR) funded by BOEM.

In the Pacific Arctic sector, vessel-based surveys have increased since 2006, due largely to an increase in physical and biological studies associated with oil and gas exploration and drilling plans (from Kuletz and Karnovsky 2012). In Sigler et al. (2011), analysis of seabird distribution at sea found three major species clusters, with the north Bering Sea and Chukchi Sea birds forming one group and the central and southern Bering Sea regions another, while the Beaufort Sea birds formed a distinctly separate group. The north Bering-Chukchi region was dominated by planktivorous birds (*Aethia* auklets in the north Bering Sea and *Puffinus* shearwaters in the Chukchi Sea), whereas the Beaufort seabirds were primarily piscivorous and circumpolar in distribution. Seabird survey data are available through the North Pacific Pelagic Seabird Database (NPPSD; see Appendix G1.3b Seabirds).

Our collaborator Kathy Kuletz (USFWS) is contributing new information in a SOAR synthesis paper on seasonal and spatial patterns of marine seabird and mammal distributions in the Pacific Arctic. She combined survey data for birds and mammals for 2007-2012 and two seasons (summer and fall) that were used to statistically identify "hotspots" for bird or mammal species, or foraging guilds for birds. Survey data were combined and gridded into 40 x 40 km cells, although recognizing that fine-scale habitat use gets lost at this scale. Hotspots for bowhead whales and walruses were compared as an example, as well as surface feeder bird groups and a diving species (crested auklets). "Shared" hotpots for birds and mammals were mapped and were identified at the head and mouth of Barrow Canyon and southern Hanna Shoal in the summer and the Barrow Canyon mouth in fall. Hotspots for mammals were generally farther north and east into the Beaufort Sea. Bird hotspots were more southerly (southern Chukchi). Many species had hotspots in/near Barrow Canyon, south Hanna Shoal-Wainwright, Hope Basin, and Bering Strait. Hotpots are typically dominated by 1 or 2 species. We consider these types of observations as ideal starting points for synthesis and connection studies. These results are part of a contributed manuscript for the SOAR effort, and could be provided as gridded bird data for other synthesis activities.

There have also been targeted at-sea surveys conducted for eiders in the northern Bering Sea by USFWS Migratory Bird Management Program, as well as nearshore aerial surveys conducted for eiders along the barrier islands and lagoons of the North Slope. There are also land-based point counts of off-shore migrating eiders conducted by the North Slope Borough during fall.

3. Seabirds as Indicators of contaminants. Murre eggs have been key to the study of atmospheric deposition of mercury in remote areas. Isotopic composition of mercury in murre eggs (a reflection of the female bird's diet in spring) showed that the deposition increased with latitude, and was negatively correlated with sea-ice cover (Point et al. 2011) (from Kuletz and Karnovsky 2012). Loss of sea-ice cover could accelerate the amount of biologically accessible methylmercury throughout the food chain (Point et al. 2011). Although seabirds transport beneficial nutrients to land, Arctic seabirds may also be responsible for transporting contaminants from their ocean foraging sites to land-based colony areas. Blais et al. (2005) found that arctic ponds near large colonies of northern fulmars (*Fulmarus glacialis*) had higher levels of persistent organic pollutants and mercury. Blais et al. suggest that contaminants in seabirds could be an indicator of ecosystem health, but are also a direct concern to indigenous peoples relying on traditional foods.

Seabirds, as apex predators in the marine environment, provide a valuable and relatively convenient means of monitoring contaminants in major marine regions through analysis of seabird egg specimens. In 1999, the USFWS-AMNWR, the USGS and NIST implemented the Seabird Tissue Archival and Monitoring Project (STAMP**;** http://www.nist.gov/mml/csd/seabirdeggs.cfm) to monitor contaminants in Alaska's marine environments. The project was designed as an ongoing long-term effort to track geographic and temporal trends in environmental quality by collecting Alaskan seabird eggs using standardized protocols, processing, and banking of samples under stable conditions to determine baseline levels of persistent bioaccumulative contamints, banked at the Marine Environmental Specimen Bank.

STAMP is a contributor to the Arctic Monitoring and Assessment Programme and in 2008 was designated as a component of the international AMAP/CAFF Coordinated Monitoring Effort. Additional information on arctic marine birds in the PacMARS area is available through the CAFF/Arctic Council as part of the Circumpolar Seabird Expert Group (see Appendix G1.4. Biodiversity Programs).

A3.2.3 Demersal fishes

1. Demersal fisheries-General Approach. Fishes are often the fauna best known in any marine area with a commercial, regulated and managed fishery. The PacMARS area, in contrast, has no commercial harvest of demersal fishes, and information on the abundance, biomass and diversity of fishes has, therefore, been poor until recently in comparison to the well-surveyed southeastern Bering Sea (Norcross et al. 2013a). Since the early 2000s, a number of studies have focused on fishes (Mecklenburg et al. 2007, Norcross et al. 2010, 2013b) because of three major reasons: (1) the increased interest in industrial exploration of the PacMARS area, specifically related to recent oil and gas lease sales in the northeastern Chukchi Sea and the US Beaufort Seas (e.g., Day et al. 2013), (2) the recently implemented Arctic Fisheries Management Plan (NPFMC 2009), and (3) the documented and anticipated northern extension of fish species and communities (Mueter and Litzow 2008, Hollowed et al. 2013). The PacMARS PI team does not include a fish expert, but has consulted Fisheries Oceanographer Dr. Brenda L. Norcross (School of Fisheries and Ocean Sciences, University of Alaska Fairbanks) who has conducted extensive data synthesis and new studies on demersal fishes in the PacMARS region with her collaborators. For details on syntheses for the Chukchi and Beaufort Seas, we refer readers to Norcross et al. (2013a), Logerwell et al. (2011) and other cited publications. The body of literature on the key role of Arctic cod in the Arctic food web, and its physiology and biochemistry has been growing steadily over the past decade but is not reviewed here.

2. Arctic Integrated Ecosystem Survey (ArcticEis). The overall goal of these annual surveys in the NE Bering and Chukchi Seas is to contribute to a comprehensive assessment of the oceanography, lower trophic levels, crab, and fish communities and to evaluate results relative to past and ongoing studies in the same area (Fig. A7). The primary purpose of the surveys is to gather data needed to avoid or mitigate effects of potential future offshore oil and gas development projects on marine life. The collected data will help guide future decisions related to economic develop activities in the region, including transportation, increased fisheries activities, and impacts of climate change on the Arctic marine ecosystems. The Arctic EIS project is funded primarily by BOEM, with support from NPRB and NOAA. Data from these surveys are being used in SOAR upper trophic manuscripts (Appendix G2).

3. The Bering-Aleutian Salmon International Survey-II (BASIS-II) is the North Pacific Anadromous Fish Commission (NPAFC) coordinated program of cooperative research on Pacific salmon in the Bering Sea designed to clarify the mechanisms of biological response by salmon to the conditions caused by climate changes. Recent fluctuations in the abundance, survival, and growth of salmon in the Bering Sea have occurred coincidently with fluctuations in the physical and biological oceanographic conditions. The BASIS survey of the Bering Sea epipelagic ecosystem was designed to improve our understanding of salmon ecology in the Bering Sea and to clarify mechanisms linking recent changes in ocean conditions with salmon resources in the Bering Sea. Further details and weblinks are available in Appendix G1.3c.

4. The Ecosystem Monitoring and Assessment (EMA) Program (NOAA)

The Ecosystem Monitoring and Assessment (EMA) Program within NOAA has an overall goal is to improve and reduce uncertainty in stock assessment models of commercially important fish species through the collection of observations of fish and oceanography. Observations for fish include abundance, size, distribution, diet and energetic status. Oceanographic observations include conductivity-temperature at depth, nutrient levels, and estimates of the composition and biomass of phytoplankton and zooplankton (includes jellyfish) species. These fish and oceanographic observations are used to connect climate change and variability in large marine ecosystems to early marine survival of commercially important fish species in the Gulf of Alaska, Bering Sea, and Arctic. The Alaska Fisheries Science Center's Ocean

Carrying Capacity Program is responsible for BASIS research in U.S. waters. The Northeastern Bering Sea EMA program uses pelagic trawls, mid-water acoustics and oceanographic data collected during the Northern Bering Sea survey to improve understanding of the pelagic ecosystem and assist efforts aimed at reducing uncertainty in harvest management of fishery resources important to Alaskan commercial and subsistence fisheries. The Arctic/Chukchi Sea Ecosystem Assessment EMA

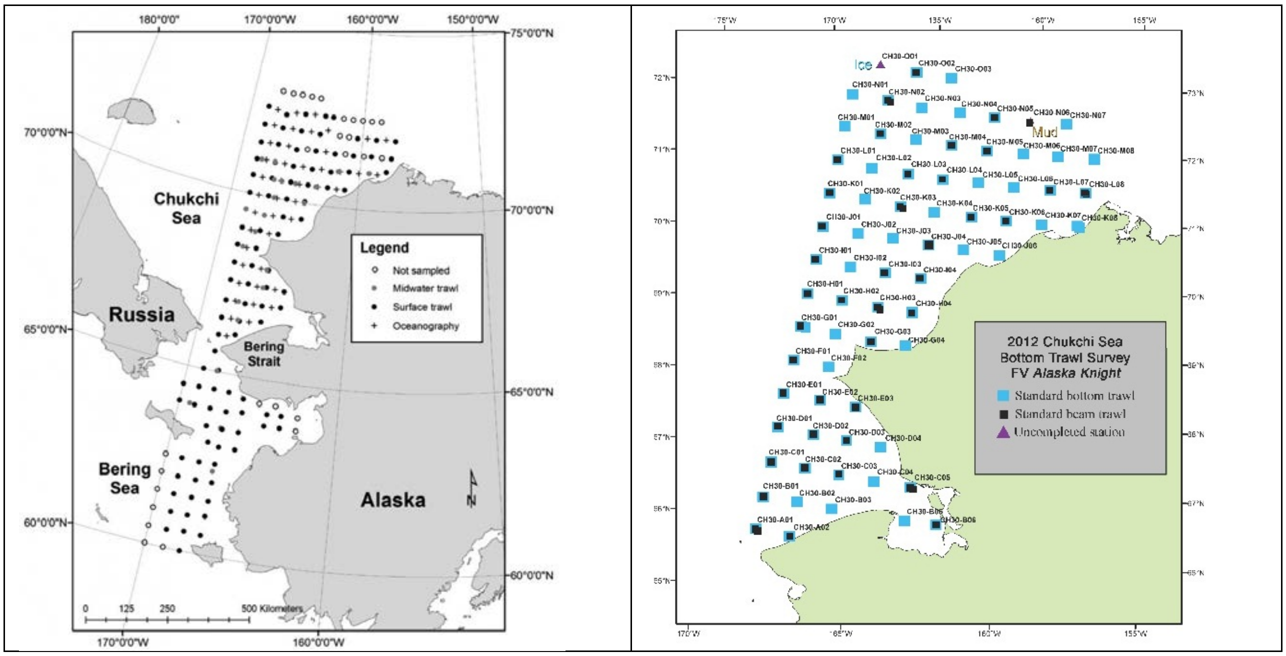


Figure A7. Left panel. The 2012 surface trawl cruise station map while on board the F/V Bristol Explorer. Right panel: The 2012 bottom trawl cruise station map while on board the F/V Alaska Knight. (Credit both maps: AFSC).

program in the Chukchi Sea and Arctic is investigating ecosystem status and trends with the continued loss of sea ice and to study its effect on the distribution, migration, energetics, and survival of commercially important fish species in the Bering Sea/Chukchi Sea. Scientists within the EMA Program partnered with the University of Alaska Fairbanks, School of Fisheries and Ocean Sciences to provide a comprehensive assessment of the northeastern Bering Sea and Chukchi Sea (NEBS/CS) ecosystems including the physical environment, the primary and secondary producers that support Arctic marine food webs, and the numerous fish species utilizing the area beginning in 2012. Further details on the NOAA EMA and partner activities and weblinks are available in Appendix G1.3c.

A4. Background on PacMARS Ecosystem Components

A4.1 Physical data: sea ice, physical oceanography, and hydrography (Themes 1 and 2)

Physical oceanographic features can be relatively well understood and predictable relative to other oceanographic disciplines, and a high-volume of electronic data are available from multiple cruises and moored or ice-tethered instrumentation (Fig. A8). Considerable variability exists however, and any synthesis of the available data should seek to resolve existing information in order to define the dominant current/advective fields and hydrographic features, such as seawater temperature, salinity, density, and current fields (e.g., see Pickart 2004 for an example of the complexities in determining a mean current field). As with other variables examined in this study area, the data are limited seasonally, with greatest spatial extent available during the spring-to-early fall period when ice cover permits the most ship-based sampling. Data were combined and used to calculate mean fields of hydrography, including depth of the pycnocline and velocity. Ultimately, these fields can then be compared to biological data sets as part of research theme exploration and development.

The proximate coastal domain, including the shoreline itself and closely associated estuarine waters, are recognized as some of the most threatened ecosystems on Earth (Lantuit et al. 2011), and represent an important interface between marine, cryospheric, terrestrial, atmospheric and social systems**.** The coastal domains extending from the northern Bering Sea to the Chukchi Sea are shallow and warm through the spring to fall season, with seawater temperatures colder to the north, and along the Beaufort Sea coast. Salinity gradients are a defining feature of the Arctic Ocean well beyond the nearshore environment (McClelland et al. 2012), but climate change impacts are anticipated to have particularly profound effects near the land-sea interface. In many areas, nearshore ice conditions are changing (AMAP 2011), erosion of coastlines is increasing (Jones et al. 2009), permafrost is warming (AMAP 2011), landscapes are slumping (Shiklomanov et al. 2012) and drying (Lin et al. 2012) or becoming warmer and greener (Bhatt et al. 2010) and the extent, duration and intensity of ocean acidification (OA) events are increasing (e.g. Fabry et al. 2009).

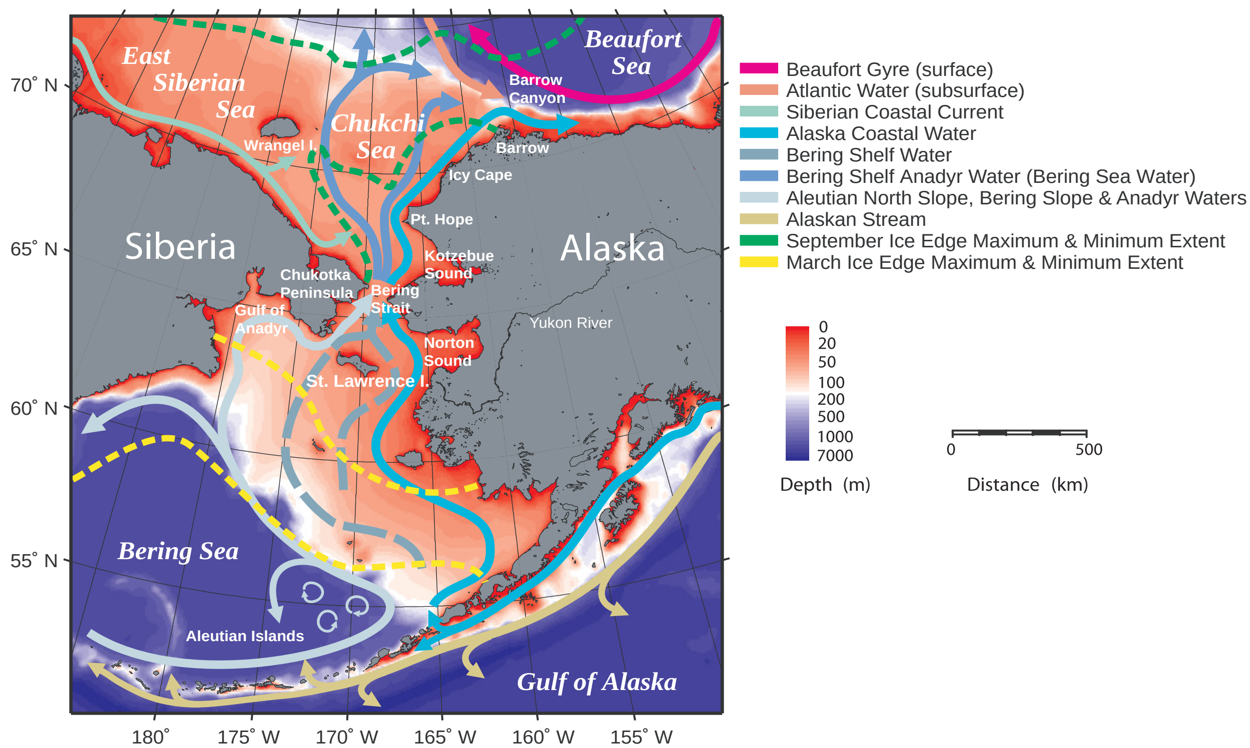


Figure A8. Schematic of water mass type and sea ice extent in the northern Bering, Chukchi, eastern Siberian Sea and western Beaufort Seas (modified from map provided by Tom Weingartner and Seth Danielson, University of Alaska Fairbanks).

A4.2. Phytoplankton and zooplankton standing stock and primary production

We used this synthesis opportunity to review newly assimilated data, as well as known sources to: 1) determine the spatial distribution of phytoplankton standing stock (chlorophyll) and the abundance and biomass of selected copepod species/life stages for different periods during the year across the region, 2) determine the associations of variations in the above with mean hydrographic fields, 3) start to identify hot-spots of phytoplankton and zooplankton abundance/ biomass/production, 4) determine associations between phytoplankton and zooplankton standing stocks and other biological variables such as benthic biomass and the distribution of zooplankton predators, and 5) used the above analyses to address the chosen research themes. We included all available current and historical data sets in the analysis, including those collected prior to the 2000s, which were collected with methodology appropriate to be comparable to the other data (e.g., net mesh size). The data were separated into different periods seasonally (e.g., spring, summer). These fields were mapped geographically and will be compared to each other (e.g., phytoplankton and zooplankton, different species/taxa of zooplankton) on a point-to-point basis as well as to other biological variables (e.g., benthic biomass, abundance of seabirds) and to mean hydrographic fields. The fields will provide a set of abundances across the geographic range of the data for each variable that can be used quantitatively in comparisons and correlations.

A4.3 Phytoplankton and zooplankton biodiversity and upper trophic feeding hotspots

In marine ecosystems, biodiversity loss has been documented to decrease ecosystem services such as the capacity to provide marine fisheries (Worm et al. 2006). Biodiversity-productivity relationships remain largely undocumented for the Arctic (see Witman et al. 2008 for one exception), but elsewhere diversity either increases monotonically with productivity (Mittelbach et al. 2001) or the relationship is hump-shaped with highest diversity at intermediate productivity levels (Waide et al. 1999). In the past few decades, data sets on Arctic marine biodiversity (species richness) and measures of primary productivity have been compiled (e.g. Bluhm et al. 2011a, Matrai et al. 2013) and lend themselves for synthetic analyses.

Many recent efforts to examine food webs have incorporated the functional role of different organismal groups, or guilds, in the biological processing of organic matter within the western arctic shelf ecosystem (e.g. McTigue and Dunton 2013). This approach has the advantage of providing a mechanistic method to assess species-level function in the Chukchi and Beaufort Seas, but does not provide information for individual species that is critical in the assessment of change. This food web analytical approach facilitates evaluation of the large spatial scale patterns in species dependency on carbon sources and changes in trophic level. Variations in stable carbon and nitrogen isotopic compositions provide important clues to the origin of plant or algal carbon and the cycling of carbon and nitrogen, particularly in the benthos. The cycling and processing of organic matter, and how it is delivered to higher trophic levels has become an increasingly important research topic, along with the realization that marine food webs can be more realistically described as a “trophic continuum” rather than having discrete trophic levels. Our PacMARS synthesis includes incorporation of stable isotopic data relevant to these food web analytical approaches that has been conducted over the past several decades in the Chukchi and Beaufort Seas with support from both federal agencies and industry. Compilation of these data was perceived as an important exercise for developing a baseline to assess future changes in trophic structures in different areas across the western arctic. These data can also be used to help us identify the predominant organic matter sources assimilated by benthic and pelagic fauna.

Numerous studies have addressed the organic matter assimilation pathways in benthic food webs within high latitude marine systems in the Alaskan Arctic (e.g. Dunton et al. 1989, Dunton and Schell 1987, Dunton et al. 2012, Feder et al. 2011, Iken et al. 2010, Lovvorn et al. 2005, McConnaughey and McRoy 1979). Tracing assimilation pathways from primary producers is essential to understand how higher trophic level organisms (e.g., marine mammals, birds, fish) obtain their ultimate energy sources. The assimilation pathways that lead to apex predators are particularly of interest since their ultimate energy sources (primary producers) are heavily dependent on and regulated by sea ice dynamics. Although many studies relate climate change effects to responses of primary producers in arctic ecosystems (e.g. Arrigo et al. 2008, Kahru et al. 2011, Wassmann and Reigstad 2011), it is more unusual for the equally important question of how higher trophic organisms with different feeding modes may be affected (Sun et al. 2009).

Stable carbon and nitrogen isotope analyses are used to identify the ultimate sources of carbon that are critical components of consumer diets and to track the transfer of assimilated organic matter among organisms. Because of the consistent, stepwise fractionation or enrichment exhibited by heavy isotopes of carbon and particularly nitrogen during biological processing, these analyses are reliable tools to investigate food web dynamics (Fry and Sherr 1984). $\delta^{13}C$ values between source and consumer change approximately 0-2‰ (per mil) per trophic step (DeNiro and Epstein 1978, 1981, Post 2002). Since the primary produced sources of carbon often have distinct $\delta^{13}C$ values, and fractionation per trophic step is small, stable carbon isotopes can act as tracers of carbon sources from the original production. Stable nitrogen values ($\delta^{15}N$) of organisms become enriched by 3-4‰ per trophic step (DeNiro and Epstein 1981). Consequently, $\delta^{15}N$ values are used to verify trophic position in a food web (Post 2002, Vander Zanden and Rasmussen 2001). Stable isotope analysis provides an advantageous tool because it not only uses a long-term, integrated tracer within organisms, but also distinguishes between food source assimilation versus ingestion as indicated by gut contents analysis. Moreover, organic matter assimilation pathways represent the same avenues that organic contaminants, such as polycyclic aromatic hydrocarbons (PAHs) or heavy metals associated with oil and natural gas development are transferred and biomagnified in the food web (Hoekstra et al. 2003, Rasmussen et al. 1990).

A4.4 Infauna

Benthic infaunal biomass reflects interannual carbon deposition to the seafloor on the shallow Chukchi Sea continental shelf (Grebmeier et al. 2006a and references therein, Grebmeier 2012). The northeast outer continental shelf of the Chukchi Sea and the head of Barrow Canyon are at the interface of the Chukchi and Beaufort Seas outer shelves and slope regions and are a key conduit for transformed Pacific water and associated organisms that transit to the deep Arctic Basin (Grebmeier and Harvey 2005 and references therein). It is likely that large-scale ecosystem changes on the shelf, as influenced by environmental change in the Pacific inflow and ice dynamics, will affect higher trophic organisms. These large-scale changes are expected to be observable through changes in benthic prey biomass, community composition, and sediment grain size, which respond to local current speed. Sediment grain size is a key predictor of benthic faunal community composition; by comparison, sediment organic carbon, which is positively correlated with the smaller silt and clay grain particles, is a key predictor of biomass (Grebmeier and Cooper 1995, Grebmeier et al. 2006a and references therein).

Bivalves, polychaetes, and sipunculids dominate the general infaunal community of the northern Chukchi Sea, where average infaunal benthic biomass is 5-15 g C m^{-2} (200-400 g wet wt. m^{-2}; Grebmeier et al. 2006a). This contrasts with a lower biomass community dominated by foraminifera on the upper slope (200-1000 m depth), with benthic biomass <5 g C m^{-2} (<200 g wet wt. m^{-2}), and extending down into the Canada Basin (Grebmeier et al. 2006a). Notably, the northeast Chukchi Sea, including upper Barrow Canyon, is a “hotspot” for the entire Chukchi Sea, with a rich community of suspension feeding infauna and epifauna (e.g., bivalves, barnacles, basket stars, and tunicates) attached to rocks and cobble and mixed sediments, suggesting the presence of strong currents (Feder et al. 1994a, Feder et al. 1994b, Grebmeier et al. 2006a). In areas with interspersed silt, clay, and gravel, the suspension-feeding mussel *Musculus sp.* is abundant, with an individual station biomass of up to ~150 g C m^{-2} (~4000 g wet wt. m^{-2}; (Grebmeier et al. 2006a). This benthic biomass maximum at the head of Barrow Canyon coincides with extremely high sediment oxygen uptake, an indicator of carbon supply to the benthos (Moran et al. 2005, Grebmeier et al. 2006a, Lalande et al. 2007, Lepore et al. 2007).

There has been a concerted effort to improve our lower and upper trophic understanding through the COMIDA and CSESP effort in the Chukchi Sea. The BOEM “Arctic Nearshore Impact Monitoring in Development Areas (ANIMIDA/cANIMIDA/ ANIMIDA III)” efforts in the Beaufort Sea include the “Arctic Nearshore Impact Monitoring in the Development Area (ANIMIDA)” project (1999 - 2002), the “Continuation of the Arctic Nearshore Impact Monitoring in the Development Area (cANIMIDA)” project (2004 - 2007), and the new ANIMIDA III project to extend this monitoring work into Camden Bay (see http://nssi.portal.gina.alaska.edu/catalogs/3097-boem-arctic-nearshore-impact-monitoring-in-deve).

A4.5 Epifauna

Epifaunal invertebrates are defined as the boneless animals inhabiting the sediment surface rather than the interstitial sediments. They range in size from <1mm (e.g. some Foraminifera) to > 20 cm (e.g. basket stars). In this as in other works we refer to epifaunal megafauna, i.e. the fauna caught in trawl nets or photographed on under-water imagery. Most epifaunal megafauna (hereafter called epifauna) is typically of a minimum size around 5 mm on high-resolution photographs, sometimes smaller, as well as sampling using smaller mesh nets. The combination of trawls and videographic imaging is ideal for sampling this compartment of the benthos as quantitatively as possible (Eleftherious and McIntyre 2008), but for the most part, coordinated and quantitative use of both two approaches is rare.

Epifauna in the Pacific Arctic play a role in the carbon cycle through their contribution to benthic biomass, and, accordingly to carbon remineralization (references in Table A2). Epifaunal communities, in particular brittle stars, contribute as much as 25% to total benthic carbon respiration in the NE Chukchi Sea (Ambrose et al. 2001) and up to ~40% in the Beaufort Sea (Renaud et al. 2007). Where known, epifauna taxa in high latitudes including the Pacific Arctic are long-lived with age estimates ranging from ~15 years for snow crab (Shirley and Bluhm 2005), up to two decades for the bivalve *Serripes groenlandicus* (Carroll et al. 2009), and up to half a century for sea urchins (Bluhm et al. 1998, Blicher et al. 2007). Epifauna taxa can, therefore, serve as long-term integrators of climatic conditions or change thereof (Fig. A9). Sclerochronological proxies from bivalve shells, for example, have proven to serve as useful tools to retrospectively assess ecosystem variability and its biological consequences (Khim et al. 2003, Carroll et al. 2009, Ambrose et al. 2012). Lastly, several hundred epifaunal species contribute to the PacMARS region’s biodiversity (species richness) (Sirenko et al. 2009, Piepenburg et al. 2011).

Table A2. Roles of epifaunal invertebrates in the Pacific Arctic.

Role / function	Primary taxa	Example reference (not exhaustive)
Prey for marine mammals	Shrimps, crabs	Lowry et al. 1980, NAMMCO 2004, Dehn et al. 2007, Sheffield and Grebmeier 2009
Potential commercial and subsistence value	Snow crab, sea urchins	Paul et al. 1997, Rand and Logerwell 2011
Indicator of biomagnification of contaminants	Predatory snails, crabs, amphipods	Dunton et al. 2014 COMIDA CAB final report
Contribution to carbon mineralization	Brittle stars	Ambrose et al. 2001, Renaud et al. 2007
Contribution to benthic biomass	Echinoderms (brittle stars, sea stars), crustaceans	Carey et al. 1977, Frost and Lowry 1983, Feder et al. 2006, Hamazaki et al. 2005, Bluhm et al. 2009, Rand and Logerwell 2011, Blanchard et al. 2013, Ravelo et al. 2014, Ravelo and Konar in prep.
Contribution to biodiversity	Gastropods	Feder et al. 2006, Bluhm et al. 2009, Piepenburg et al. 2011, Blanchard et al. 2013
Long-lived indicators of climate variability and change	All; those with hard shells that can be aged	Sirenko and Gagaev 2007, Mueter and Litzow 2008, Carroll et al. 2009

A4.6 Biological “hotspots”

Benthic infauna that remain in place in the sediments as adults respond to variable levels of export production, building up biomass over multiple years-to-decades and maintaining persistent community patches or “hotspots” that provide important prey to mobile epibenthic animals and upper trophic level animals, particularly marine mammals and diving seabirds. Localized areas that can be termed benthic biomass hotspots occur on the continental shelf SW of St. Lawrence Island as well as between St. Lawrence Island and Bering Strait, in the southern Chukchi Sea, and in the northeast portion of the Chukchi Sea, including upper Barrow Canyon (citations in Grebmeier 2012). We define these localized biological features as annually persistent and seasonally consistent regions of high water column and

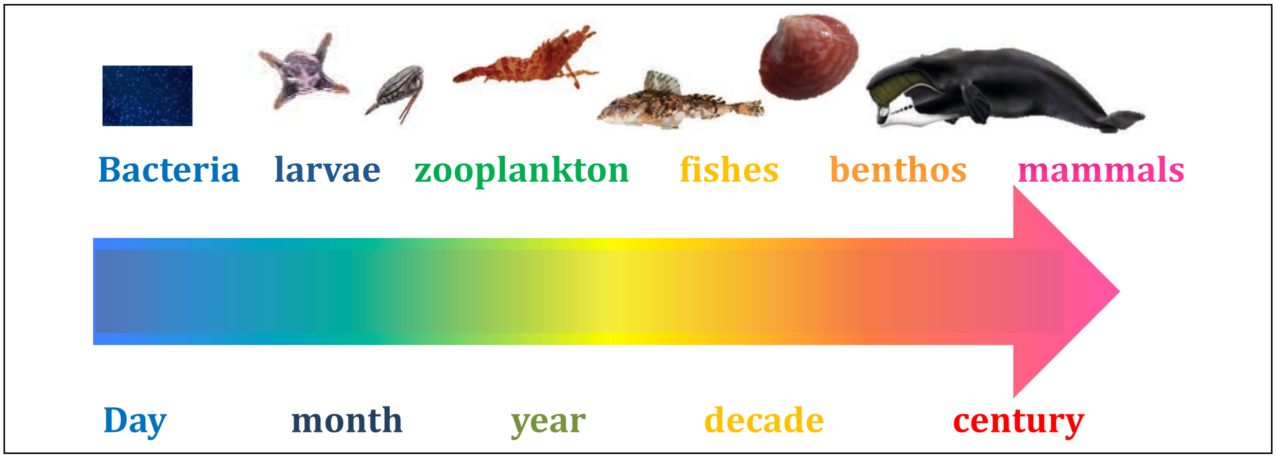


Figure A9. Longevity of different faunal components of the Pacific Arctic. The differing age spans can be used as, indicators of environmental processes extending over different time scales. Photo credits: B. Bluhm, R. Gradinger, R. Hopcroft, K. Iken (all University of Alaska Fairbanks), K. Mecklenburg (California Academy of Sciences).

benthic biomass. By comparison, biomass of both primary producers and benthic macroinfauna are diminished on the narrow continental shelf of the Beaufort Sea (Dunton et al. 2005), but these hotspot features are again present in the Cape Bathurst Polynya area of the Canadian Arctic Archipelago (Conlan et al. 2008). In the Beaufort Sea, both enhanced production (primary and secondary) occur along the outer continental slope (Logerwell et al. 2011), although they are not as well defined as the benthic hotspots on the broad continental shelves of the Northern Bering and Chukchi seas.

All of the continental shelf benthic "hotspots" are directly tied to hydrographic processes that bring high nutrients onto the shelf and support high algal production, often where a reduction of current speeds facilitate higher export production of particulate carbon to the benthos (Grebmeier et al. 2006a). Currently, cold, early season Pacific winter water temperatures limit zooplankton growth, thus minimizing the impact of the overall grazing capacity of zooplankton to crop descending carbon, with the net carbon export settling to the benthos to support high biomass benthic infaunal communities at the hotspot sites (Grebmeier et al. 2006b, 2009). Satellite and field observations indicate the annual reoccurrence of high chlorophyll blooms at the benthic hotspot sites (Hill and Cota 2005, Lee et al. 2007), whereas annual shipboard sampling provides evidence of the continued persistence of underlying relatively non-motile, macroinfaunal organisms (e.g., clams, polychaetes, amphipods) that benefit from the high carbon export to the underlying benthos at these sites (Grebmeier et al. 2006a,b, Grebmeier 2012). Although epibenthic fauna also benefit from carbon export to the benthos, there appears a disparity in connection between regions of persistent carbon export that support high infaunal populations and regions of high epibenthic populations that is still not understood (Bluhm et al. 2009, Ravelo et al. 2014).

The benthic biomass hotspot sites support benthic feeding marine mammals, such as gray whales, walrus, and bearded seals (Moore et al. 2003, Jay et al. 2012, Moore et al. 2014, Nelson et al. 2014), and in certain areas, diving seaducks (Lovvorn et al. 2009). By comparison, zooplankton hotspots are somewhat more ephemeral, but do indicate repeatable patterns of organic carbon transport. For example, those sites allowing seasonal buildup of water column biomass, such as the late spring-summer accumulations observed in the southern Chukchi Sea (Bluhm et al. 2007), water mass frontal zones, and via wind- and current-induced concentrating mechanisms (e.g. upwelling) at the slope and canyons (e.g., Barrow Canyon) and nearby shelf areas provide indicators of water-column or epibenthos biomass hotspots (Ashjian et al. 2010, Walkusz et al. 2012). Persistent advective sites, such as Barrow Canyon that is located at the interface of Pacific-produced Bering Sea waters (winter and summer types) and upwelled

Atlantic water, are important sites for pelagic-feeding upper trophic levels, including bowhead whales and seabirds (Moore et al. 2014). Although we focus on benthic biomass hotspots in the PacMARS effort, we also recognize there are key locations for concentration of zooplankton used by pelagic-feeding, upper trophic species, including bowhead whales (feeding on copepods and euphausiids), belugas (feeding on forage fish, including arctic cod), and pelagic seabirds (feeding on copepods, small fish, and gelatinous zooplankton).

Understanding biological hotspots is important in evaluating the overall system as these sites track the status and change in physical forcing, sea ice retreat, and ecosystem response in a shallow water continental shelf system that is being stressed by both climate change and anthropogenic impacts (e.g., oil development, transportation) (see Wassmann et al. 2011).

A4.7 Chemical contaminants

Contaminants are a concern in the Arctic because long-lived, top predators in this relatively pristine environment are susceptible to persistent chemicals that are biomagnified (e.g., Macdonald and Bewers 1996, Hoekstra et al. 2003, AMAP, 2011). Long-range atmospheric transport of some contaminants to the Arctic, coupled with possible release of other contaminants during offshore oil and gas activities, heighten this concern. Theme 5 of the PacMARS synthesis addresses contaminants in the northern Bering, Chukchi and Beaufort seas with the following goals: (1) establish a data base for chemical contaminants in sediments and use geochemical methods to identify areas where concentrations are above background, (2) establish a data base for chemical contaminants in selected marine biota and identify spatial and, where possible, temporal trends, in body burdens of contaminants, and (3) synthesize these results to link contaminant sources and likely transport pathways with the individual characteristics of the contaminant of interest. Contamination is defined for this synthesis as the presence of chemicals in the environment at concentrations that are above background; pollution is defined as the presence of chemicals in the environment at concentrations that cause adverse biological or socioeconomic impacts (GESAMP 1986).

Sediments are used as an indicator of regional and local environmental contamination in the PacMARS study area because they are long-term integrators of contaminant inputs. It is also possible through dating of sedimentation rates to identify episodic past events and quantify rates of deposition. The volume of data for sediments has grown steadily during the past two decades, through studies funded by BOEM and the NSF. In addition, the Office of Naval Research sponsored a radionuclide contaminants program (the Arctic Nuclear Waste Assessment Program) in the 1990s that provided insights on the re-distribution of radioactive contaminants, particularly those deposited from bomb fallout and long range transport of materials from nuclear fuel re-processing centers. Data also are available for contaminants in age-dated sediments to facilitate identification of episodic past events and to determine rates of contaminant deposition.

Techniques for identifying background concentrations of sediment chemicals that occur naturally also have become more standardized. We identify background metal concentrations using metal/Al ratios and a well-established method that has been tested with data from both the Beaufort and Chukchi seas (Trefry et al. 2003, 2013, 2014). Background concentrations of naturally occurring organic contaminants are determined as a function of sediment grain size and by compound ratios, again using techniques developed for the Arctic (Brown et al. 2004, 2010). The presence of a synthetic organic chemical in sediments at any concentration is considered contamination. The sediment portion of our contaminant synthesis establishes background concentrations as a point of reference for identifying past, present or future contaminant hotpots.

Accumulation of contaminants in biota is of more immediate concern because of the potential for direct impacts on marine mammals and humans. Data for metals and organic substances in biota from the PacMARS study area come from two different approaches: (1) multidisciplinary studies of benthic biota

and sediment chemicals with an emphasis on offshore oil and gas activities, and (2) assessments of contaminants in fish, marine mammals and birds by state and federal agencies. These studies differ in both the contaminants investigated and the supporting data acquired. Furthermore, data for contaminants in biota tend to group into the following two categories: (1) concentrations in whole organisms for use in risk assessment and (2) concentrations in specific tissues or blood to investigate internal compartmentalization or biomagnification of contaminants. The choice of tissue sample to collect and analyze is often based on convenience or, in the case of marine mammals, state and federal regulations.
Differences in chemicals studied and environmental data collected between the two approaches for biota constrain the overall synthesis as do the number of samples, locations and times of collection of tissue from a given species. Nevertheless, we contend that bioaccumulation, biomagnification and possibly temporal trends can be assessed at various trophic levels.

A4.8 Human environment

The PacMARS study region encompasses the Alaska coastal settlements stretching from Kaktovik to Nome, including Nuiqsut and the Bering Strait island communities of Savoonga, Gambell, and Diomede. Although the subsistence base of these communities includes both, the ocean and the land, it is the interactions of those communities with the marine environment that the North Pacific Research Board was most interested in for the purposes of the PacMARS effort.

The connection between the local subsistence ways of life and ocean resources is not unique to the coastal settlements within the PacMARS study region. Residents of inland communities, in Alaska and Arctic as a whole, value products from marine mammals and other organisms, which they obtain through kinship networks and customary sharing. However, the coastal Arctic environment does bring a number of unique characteristics that the communities in the PacMARS study region share. Among those are direct daily interactions with the ocean, harvesting activities and culinary practices that depend substantially on marine mammals, and heightened vulnerability to certain impacts of climate change such as coastal erosion (Schweitzer 2011) and changes in sea ice – the freeze-up and thaw regimes, depletion of multi-year ice, the increasing peril those pose for hunters and travelers (Gearheard et al 2013, Krupnik 2002, Kapsch et al 2010). Ethnographic literature from our study region teaches us that residents of the coastal Arctic view themselves being part of the marine environment. They genuinely connect the ocean health to their own health and wellbeing of their families and communities. This interconnectivity, in turn, contributes to the scope of local concerns over the impacts of the increase in commercial ship traffic and offshore industrial development (Fidel et al 2012, Gadamus et al 2013).

Section C8 of this report further elaborates on the features that contribute to making the coastal communities of Arctic Alaska a unique social-ecological environment. Its purpose is to provide an overview of the emerging perspectives on the human experience within the domain of interactions between climate change, local knowledge, subsistence way of life, and the marine environment.

B. METHODS AND DATA SELECTION CRITERIA

The PacMARS project brought together multiple data sets that were either archived individually by cruise and/or were developed as gridded data from large data sets to form the basis of our synthesis effort. These newly developed synthetic data files were uploaded to the PacMARS EOL website as either discrete summary data files and/or as digital shapefiles for display in a mapserver (geographical information system) mode. The metafiles are composed of: (1) a summary of the data set, (2) data access link, (3) additional information, included related projects, (4) listing of temporal coverage, (5) listing of spatial coverage, and (6) point of contact. The text that follows describes the specific methodology by discipline used to produce the synthetic data files, including the PacMAFS EOL data archiving protocol. The subsequent Section C. Results and Discussion presents the synthesis products and discusses the findings of our analytical effort. Section D identifies research themes, major findings, data gaps, and future directions.

B1. Physical Oceanography

An extensive, though not comprehensive, collection of CTD (and bottle) cast data acquired within the PacMARS study area (62°N – 74°N, 180° – 130°W) and covering years 1970-2013 was obtained from various archives and subsequently processed to extract/derive certain representative metrics (see Table B1.1) that characterize the temperature and salinity profiles of each cast. These representative cast data were added to a summary file accessible on the PacMARS EOL site if cast temperatures were greater than -2°C and less than 15°C, and cast salinity were greater than 1 and less than 35, and the bottom depths were greater than 5 m. CTD casts with metrics outside these ranges were not included in the summary CTD data file. Currently the summary CTD data file contains information on over 18,000 casts (Fig. B1.1).

Archived data sets from which the CTD summary data have been extracted/derived (see Appendix G1 of this final report for links, including to acronyms used here) include: BASIS, COMIDA, Mirai, UAF-Institute of Marine Science, JODC, NODC/WOD, RUSALCA, SBI, Shell, SNACS/BOWFEST, HLY1104, and Louis S. St. Laurent (see Appendix G7 for listing of abbreviations).

Table B1.1 Template of CTD summary data fie (Okkonen 2013).

Column Heading	Parameter/variable description
========	===
Cruise ID	Cruise name/number, Project name, or other identifier
Stn #	Station/cast number; -999 if none provided
Stn Name	Station name; -9999 if none provided
YYYYMMDD	Year, month, and day of cast
YYYY	Year of cast
hhmm	hour and minute of cast; 24 hour clock; UTC; -999 if none provided
Time	UTC
Toff	offset (hours) from UTC
Latitude	Decimal latitude of cast
Longitude	Decimal longitude of cast; negative (-) for West Longitude
Depth	Bottom depth/pressure (m or dbar); -9999 if missing. In some cases where no bottom depth was provided, the bottom depth was determined to be the sum of deepest depth of the CTD cast and the altimeter reading. Integer value.
Nobs	Number of samples in the cast. If this value is small compared to the Depth and the cast year is during the 1970s or 1980s, the cast data may be bottle data.
Tsfc	Temperature (°C) at shallowest valid depth (pressure) of CTD cast
Tdeep	Temperature at the shallower of deepest depth (pressure) of CTD cast or 200 m

Tcast	Temperature at the bottom of the cast.
Tmax	Maximum temperature of CTD cast
Zsfc	Shallowest valid depth (m) or pressure (dbar) of CTD cast.
Zdeep	Maximum depth or pressure of CTD cast; limited to 200 m or shallower
Zcast	Maximum depth or pressure of CTD cast
ZTmax	Depth/pressure of maximum temperature
Ssfc	Salinity at shallowest depth or pressure of CTD cast
Sdeep	Salinity at the shallower of deepest depth (pressure) of CTD cast or 200 m
Scast	Salinity at the bottom of the cast
STmax	Salinity at depth/pressure of Tmax
	Derived parameters
	If density (sigma-t) data were not provided with the cast data, the density profile was computed from the International Equation of State of Sea Water (1980). Here, sigma-t (instead of sigma-theta) is used because most casts included in this dataset were acquired at depths of less than 50-60 m. For many, if not most, casts the shallowest valid sample was acquired a meter or few meters below the surface and the deepest valid sample was acquired a few meters above the bottom. The near-surface depths at which no data were acquired were assigned the temperature, salinity, and density values associated with the shallowest valid depth. Similarly, the near-bottom depths at which no data were acquired were assigned the temperature, salinity, and density values associated with the deepest valid depth (for bottom depths less than 200 m). Cast data were interpolated to integer depths and smoothed with a 3-point (3-m) boxcar filter before computation of derivatives or integrals. Derived values were computed from values at depths shallower than 200 m.
BV	maximum Brunt-Vaisala frequency
ZBV	Depth/pressure of maximum Brunt-Vaisala frequency; assumed to be the depth of the pycnocline.
MLD	Depth/pressure at which the second derivative of the density profile is maximum. Assumed to be the depth of the mixed layer.
Strat	Stratification parameter/depth; see Fiedler, P.C., Reilly, S.B., Jewitt, R.P., Demer, D., Philbrick, V.A., Smith, S., Armstrong, W., Croll, D.A., Tershy, B.R., Mate, B.R., 1998. Blue whale habitat and prey in the California Channel Islands.. Deep-Sea Research II 45, 1781–1801.
FWC	Fresh water content (m^3). Computed as the surface-to-bottom integral of the fresh water fraction (relative to S = 34.8) at each sample depth. For casts deeper than 200 m, integration is from the surface to 200 m.
Heat	Heat content (MJ). Computed as the surface-to-bottom integral of the heat content (relative to -1.9°C) at each sample depth. For casts deeper than 200 m, integration is from the surface to 200 m.

B2. Phytoplankton and Zooplankton in the Context of Water Temperature

The phytoplankton and zooplankton component of the project focuses on products that can be used to explore PacMARS Themes 1-3 (Physical characteristics and primary production, phenology of biological production, and pelagic-benthic coupling). The goal of this component of the project is to compile data sets on phytoplankton standing stock (chlorophyll), primary production, and zooplankton (focusing on key zooplankton species rather than the entire community). These data sets then were compared and correlated with data on the physical environment, particularly hydrographic characteristics. By focusing on key zooplankton species that are either numerical or biomass dominants, we expected that environmental change detection could shed light on modifications in trophic linkages and ecosystem function.

Assembling and assimilating the data sets is an enormous task, one that had been partially completed by previous investigators (e.g., Hopcroft and Rutzen, pers. comm.; Matrai et al. 2013) and that still has not been completed by the PacMARS team since new data sets continue to be identified and incorporated into the compilations. Inconsistencies between sampling methodologies, taxonomic specificity in identifications, and temporal and spatial disparity in sampling effort added complexity and limited the

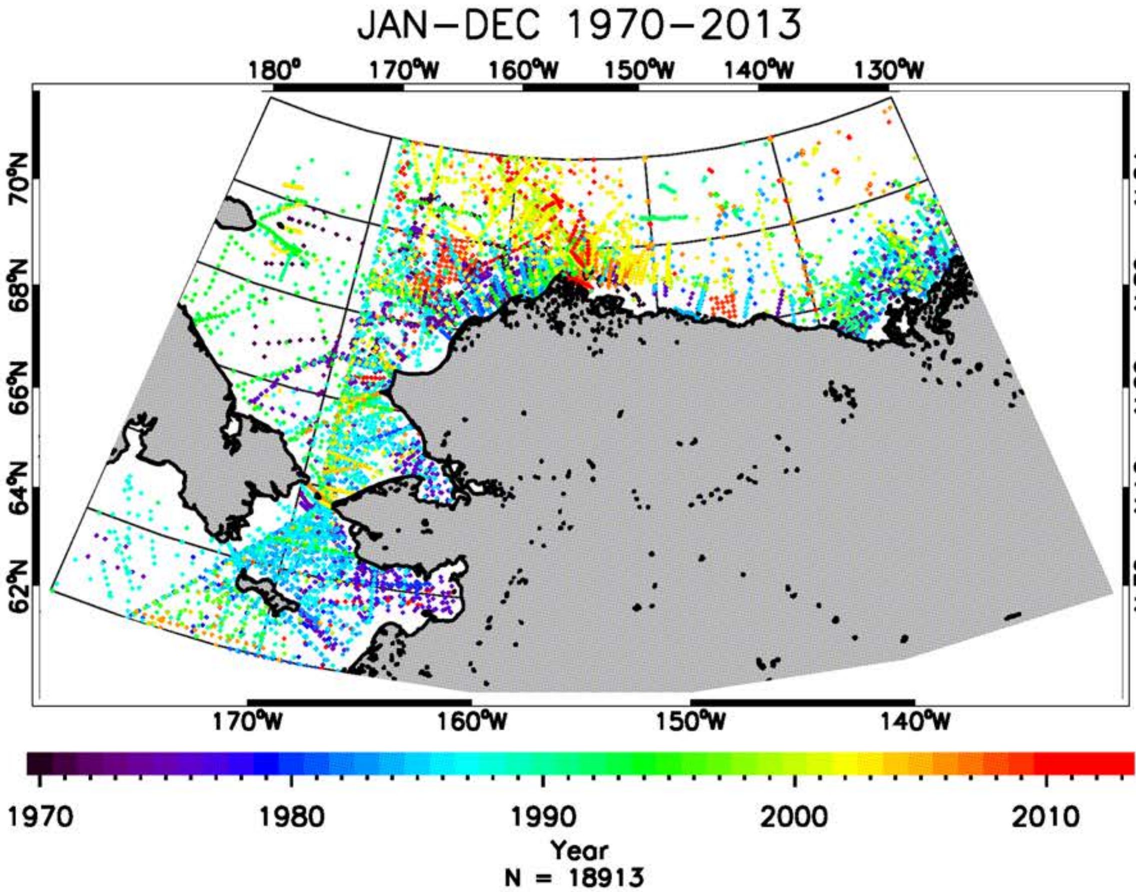


Figure B1.1 Locations of 18000+ CTD casts included in the compilation. Each cast location is color coded according to the year in which the cast was conducted.

spatial and temporal extent of the useable data. This in turn limited our ability to resolve spatial and temporal changes between recent years and years prior to the ongoing precipitous decline in summer sea ice. Lack of spatial coincidence in sampling between critical time periods (e.g., pre-2005 and 2005 and later) was a large contributor to this limitation. As the data were collected and examined, additional limitations to what we could compile became evident. For example, it quickly became clear that total zooplankton biomass would not be a realistic metric since many data sets did not include bulk measures of biomass and assigning individual weights to each life stage of each species (including non-copepods) enumerated in the abundance data was unrealistic, particularly since those weights would be size dependent and size is not usually reported. Another limitation is that the large range in the net mesh sizes, and thus the size range of organisms collected, made the majority of sample collections incomparable.

Consideration of zooplankton data was focused on including all life stages of the key species; the intent was to provide a comprehensive picture of biomass distributions and temporal/spatial changes.

B2.1 Treatment of the data sets

Data were compiled from as many data sets as were available and processed to display the identified metric for that data (e.g., upper 100 m water column integrated chlorophyll inventory). For some data, there was sufficient data density to separate the data by those collected prior to 2005 and those collected during 2005 and afterwards so that there was spatial overlap in the locations where data were collected during the two periods. The year 2005 was chosen as the differentiating year because summer sea ice extent, and presumably associated biological and physical ocean characteristics, changed markedly during and after that year relative to previous years in the satellite record. The data were gridded to a 23 x 30 grid at 2 deg. longitude and 0.5 deg. latitude spacing within the geographic range of 63.5 to 78°N and -180 to -135 °W. Gridding was done using a Fortran interpolation routine. Latitude and longitude values were transformed into values relative to the maximum and minimum of each (between 0 and 1) so that equivalent scales would be used in the interpolations.

Unless otherwise noted, bottom topography for the maps was derived from the ETOPO2 global relief data available at the NOAA National Geophysical Data Center (ETOPO2 v2). For some plots, the IBCAO v.3 500x500m data were used (Jakobbsson et al., 2012), however this topography extends south only to 64°N, just to the north of the geographic range used in these analyses.

B2.2 Phytoplankton (chlorophyll)

The core source for the chlorophyll data compilation is the high-quality chlorophyll data set that was compiled by Paty Matrai and colleagues and that is archived at the NODC (Matrai et al., 2013). This data set includes many chlorophyll data in the region that were collected through 2004 and was extensively quality controlled. A number of other data sets collected since 2004 were compiled for the PacMARS synthesis, including data collected during the RUSALCA, CSESP, AON, and ICESCAPE programs and by Canadian and Japanese expeditions (see Chlorophyll Dataset Compilation Table, C2.1). Some other available chlorophyll data from the region are discussed in Section B3.

Chlorophyll data were integrated over the upper 100 m or to the bottom where the bottom depth was less than 100 m. At least 3 observations were required to conduct an integration. Nineteen additional data sets were synthesized with the Matrai data. An additional three data sets could not be used because of insufficient resolution or information in the depth data or because the archived data were integrated over a different depth range (e.g., Arctic Ocean Section data, see Chlorophyll Dataset Compilation Table, C2.1). Data were considered separately for the periods prior to 2005 and 2005 and later and for the annual time periods of January-March, April-June, July-September, and October-December.

B2.3 Zooplankton

Zooplankton biomass was chosen as a key parameter since biomass can be used to estimate ingestion, grazing rate, development rate, and secondary production, once appropriate empirical relationships are developed. Zooplankton data usually are archived only as abundance (# m^{-3}), although some data sets do include zooplankton biomass (e.g., CSESP data collected by R. Hopcroft). As a first step, zooplankton abundance data sets from the region of interest were collected from a number of data archives and individual PIs and collated. A total of 87 data sets were identified for the analysis (Table C2.1).

Each data set was examined to determine if it met the following criteria that would allow us to use it in our analysis: 1) Organisms were identified to genera/species and life stage or at least life stage groups so that sizes could be estimated, 2) The sample integrated the water column from the surface to near bottom or to 100 m in deeper water, 3) The volume of water that was sampled and the depth of the tow was recorded, and 4) The appropriate mesh size to collect the target organism was used (75% of width). We also assess the usefulness of the individual zooplankton data sets that were compiled for the analysis in the Zooplankton Data Set Compilation file archived in the EOL PacMARS data site.

Four common copepod species groups were chosen for the analysis. *Calanus glacialis/marshallae* is a species complex of large lipidic copepods that inhabits the shelf and slope seas in this region. It generally dominates the zooplankton biomass on the outer shelf and slope regions (Campbell et al. 2009; Hopcroft et al. 2010). Based on genetic analysis, *C. glacialis* is the dominant form in the Chukchi/Beaufort Sea region and contrary to reports in previous papers, the Bering Sea as well (Campbell, Gelfman, and Ashjian, personal communication). *Pseudocalanus* spp. is a species complex that consists of up to four different species including, *P. acuspes, P. mimus, P. minutus, and P. nemanii* (Frost 1989). *Pseudocalanus* is rarely identified to species in the data sets and when it is only adult females are distinguished. It is a small copepod that is found throughout the study region and is often the second most important species in terms of biomass, although, in the inner shelf regions it is often dominant (Campbell et al. 2009, Ashjian and Campbell unpublished). *Metridia* spp. consists of two species: *M. pacifica*, an expatriate from the Bering Sea, and *M. longa*, the Arctic endemic. These are medium sized copepods that are more predatory than the other species groups (Campbell et al. 2009). They are much easier to separate taxonomically than either the *Calanus* or *Pseudocalanus* groups and are often identified to species in the data sets. *Oithona similis* is the final species chosen for analysis. This species is the most important member of the *Oithona* genus in this region and is easy to identify taxonomically, and so it is almost always identified to species in the data sets. It is a small species, smaller than *Pseudocalanus*, and thus normally not very important in terms of biomass; however, it can be extremely important numerically. Like *Pseudocalanus* spp. its younger life stages are often severely under-sampled by the most common used zooplankton nets that generally employ mesh sizes of 150-µm or greater.

Once the data sets that met the first three criteria and could be used in the analysis were identified, the species/life stages that would be quantitatively collected by the different mesh sizes needed to be resolved so that only those stages would be included. In order to do this, the prosome widths of all species/life stages of interest were measured from archived images of live animals collected from the region from prior projects of PacMARS investigators (Campbell and Ashjian) (SHEBA, SBI, SNACS/AON; see Appendix G1.6 for more specifics on prior projects). In cases where images for a particular life stage were not available, generally younger stages of the smaller species, their widths were measured from archived preserved samples. The minimum mesh size that would quantitatively collect a particular species/life stage was set to be 75% of the mean copepod width as recommended by Omori and Ikeda (1984). Only those net samples that would quantitatively collect the species/stages of interest were used in the analysis (Table B2.1).

All zooplankton abundances by species/life stage were converted to numbers m^{-2} integrated over the upper 100 m or to the depth of the net tow in shallower locations. To convert to carbon biomass the integrated abundances were multiplied by the mean carbon weight for that species/life stage (Table B2.2). The individual species/life stage carbon weights were largely taken from PacMARS investigators (Campbell and Ashjian) data sets collected during prior projects. For missing values, generally for younger stages of the smaller species, the ratio of the weight of life stage of interest to the adult female weight for closely related species taken from the literature was used to estimate the carbon weight for that stage. The biomasses for the individual stages that were quantitatively collected by the net were then summed to estimate the total biomass for that species.

Of the 87 identified data sets, and varying with species, only about a third could be used in the analysis because the others did not meet our criteria. There were several reasons that data sets failed to meet the criteria including: inappropriate mesh size (37 data sets), poor taxonomic resolution (10), no life stage data (16), water column not integrated (6), and other miscellaneous reasons including unavailable data sets for ongoing projects (6). Many data sets failed on multiple criteria. The choice of life stages for each species that were used in the analysis was a compromise between maximizing the number of data sets that could be used and the desire to include as many life stages in the analysis as possible. Therefore C1 through adult were included for *Calanus glacialis/marshallae*, C3 through adult for *Pseuodcalanus* spp. and *Metridia* spp., and only adults for *Oithona similis*.

Table B2.1 The mean width of different life stages for the copepod species/species complex used in the analysis (Top). Minimum mesh size required to quantitatively collect each life stage (Bottom).

Stage	*C. glacialis / marshallae*	*M. longa*	*M. pacifica*	*Pseudocalanus* spp.	*O. similis*
Width, μm					
C1	280	165	127	124	84
C2	362	195	150	156	100
C3	495	275	212	204	124
C4	709	360	279	216	132
C5	1000	650	497	312	164
Male	1014	945	712	330	160
Female	1136	945	712	400	196
Appropriate mesh size, μm (0.75 x copepod width) for quantitative collection					
C1	210	124	95	93	63
C2	271	146	113	117	75
C3	371	206	159	153	93
C4	532	270	209	162	99
C5	750	488	373	234	123
Male	760	709	534	248	120
Female	852	709	534	300	147

Table B2.2 Mean carbon weight (μg) for different species/species complex life stages used in the analysis.

	C. glacialis / marshallae	*M. longa*	*M. pacifica*	*Pseudocalanus* spp.	*O. similis*
Carbon wt, μgC					
C1	6.3	4.3	2.0	1.2	0.38
C2	10	6.7	3.1	1.9	0.48
C3	41	16	7.5	3.0	0.59
C4	118	42	20	5.0	0.75
C5	340	91	42	9.9	1.0
Male	228	172	80	17	1.3
Female	380	172	80	17	1.3

B2.4 Water temperature and salinity

Temperature and salinity data from the PacMARS CTD compilations (Fig. B2.1) were analyzed in the same manner as the assembled chlorophyll and zooplankton data in order to provide gridded products at the same spatial scales for all available data. There was sufficient data coverage from pre-2005 and 2005 and later to consider those two periods separately. Surface (shallowest data point in each cast), bottom, and average water column temperatures and surface and bottom salinities were considered. Average water column temperature was calculated from the heat content (see CTD data compilation file) as follows:

AvgT (°C)=(heat content)/(water column depth*4.09))-1.9

Since the biological analyses focused only on the summer period (July-September) when sufficient data were available, only that period was considered for the temperature analyses. Comparisons between the pre-2005 and 2005 and later periods were done between the gridded values at each grid cell common to both periods.

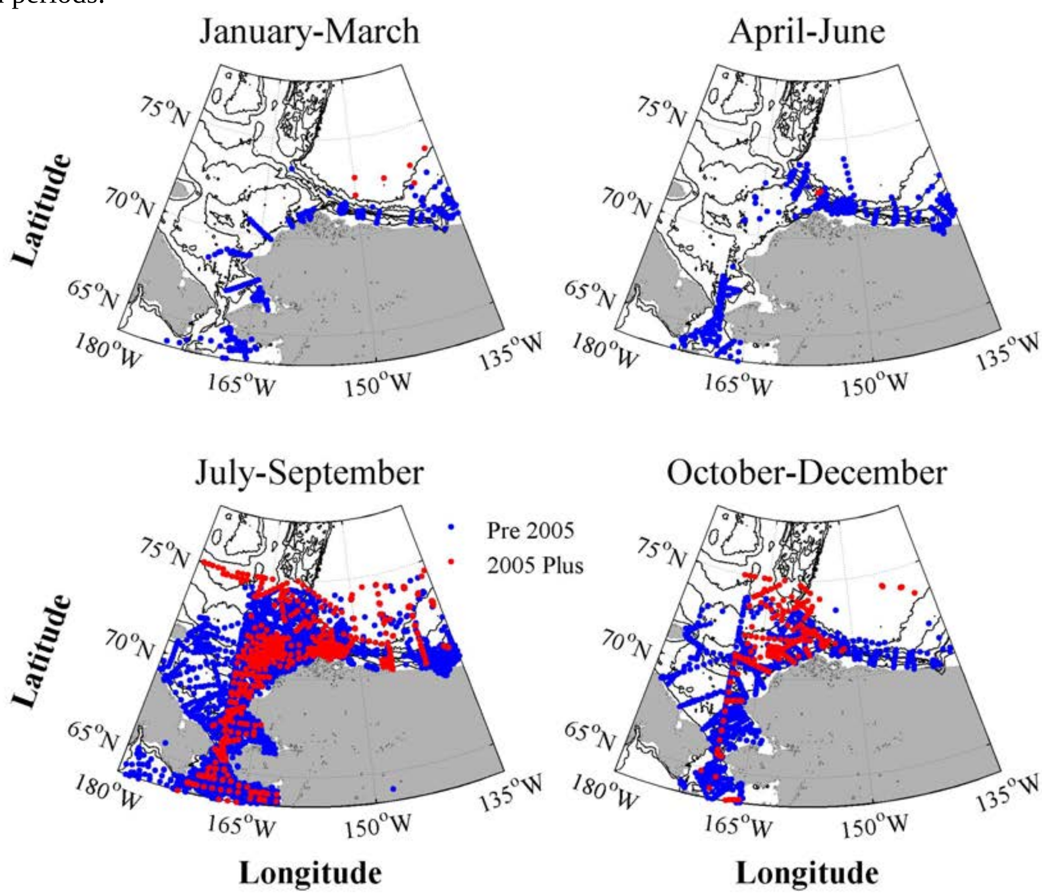


Figure B2.1 Locations of CTD casts included in the compilation. Locations are separated out by months of the year in which the casts were conducted and by year (pre-2005 and 2005 Plus). Altogether, 11765 casts are included. File=CTD_Positions.jpg

B3. Other Water Column Chlorophyll Data, Bottom Water Nutrients, Macroinfauna and Sediments

A number of interdisciplinary oceanographic cruises have been undertaken in the northern Bering and Chukchi Seas over the last four decades that have contributed to benthic ecosystem analysis, with more limited studies in the East Siberian and Beaufort Seas (Fig. B3.1, Table B3.1). Many of these cruises collected both water column and benthic parameters as part of an ecosystem approach, and we provide a tabulation of cruises used in our synthesis effort in Table B3.1 with citations for publication for specific methodologies used and/or original data sets. For our synthesis analysis, we focused on cruises during which macroinfauna were collected, preserved, and sorted in a standardized way. Summary data on integrated chlorophyll *a* and bottom water nutrient concentrations from these cruises are available to support analysis of benthic macroinfaunal communities. In addition, we accumulated data sets on sediment parameters, including sediment community oxygen consumption (SCOC) as an indicator of carbon supply, sediment grain size and total organic carbon content. These combined measurements

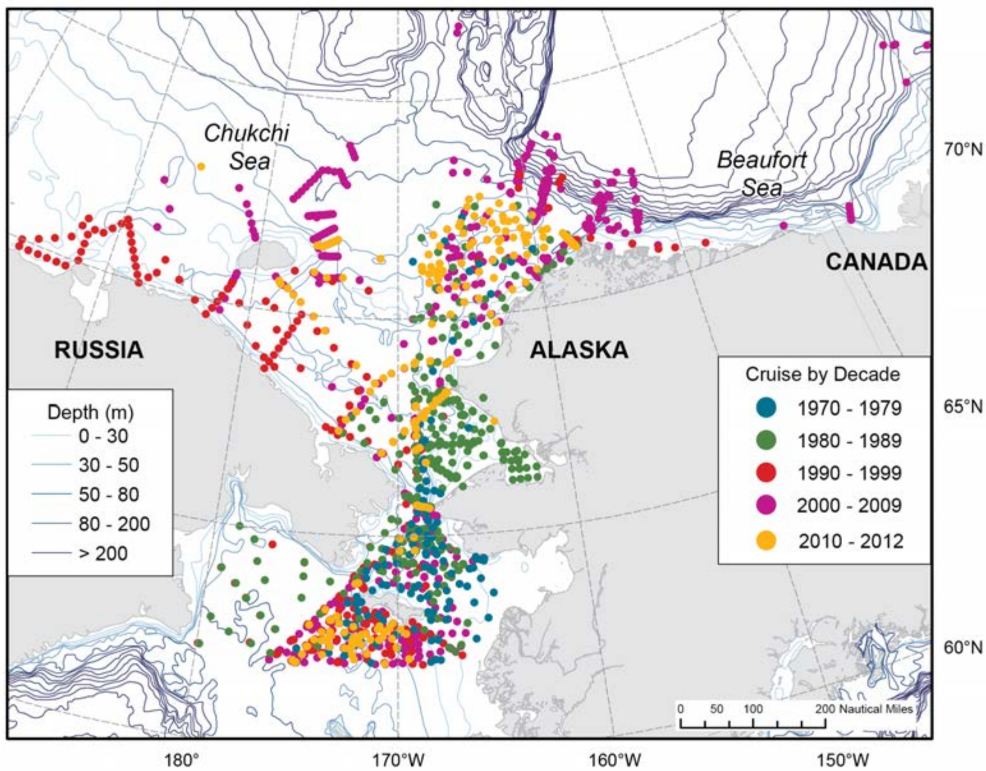


Figure B3.1 Distribution of stations for collections of water column (integrated chlorophyll a, bottom nutrients), macroinfaunal populations, and sediment parameters in the Pacific Arctic region from 1974-2012. Table B3.1 tabulates the cruises used for this composite data set.

contribute to development of a broad-scale, ecosystem-level understanding of the Pacific-influenced Ameriasian Arctic benthic ecosystem.

Benthic studies synthesized during the PacMARS effort were primarily undertaken with a single or double 0.1 m^2 van Veen grab (e.g., Grebmeier et al. 2006a, Blanchard et al. 2013) and the 0.25 m^2 OKEAN grab used by Russian scientists (e.g., Sirenko and Koltun 1992), with fauna subsequently preserved in 10% buffered seawater formalin. Only samples where all organisms from the collection were analyzed were used, and the generated data included composition, abundance and biomass. These types of benthic sampling equipment, such as van Veen grabs, have a good record of documenting the population structure and biomass of macrofaunal communities (Feder et al. 1994a, 2006, 2007, Stoker 1978, 1981, Grebmeier et al. 1989, 2006a, Sirenko and Koltun 1992, Grebmeier and Cooper 1995, Blanchard et al. 2013).

Due to bioturbation in shelf sediments that quickly mixes surface materials, van Veen grabs can also be used to estimate certain sediment characteristics for surface sediments. Collections made with cores and grabs at the same locations on the Bering and Chukchi continental shelves have been shown to not be statistically different for activities of the anthropogenic radionuclide ^{137}Cs (Cooper et al. 1998) and in most cases sedimentary chlorophyll (Pirtle-Levy 2006). For this reason, we use surface sediment data collected from the top of van Veen grabs before they are opened interchangeably with core top surface sediments for grain size and other grain size interpretation. Since grabs can be much more quickly deployed than cores that are used for sedimentation analysis and other undisturbed coring applications, use of surface sediment data from grabs also improves the power of available analyses.

Table B3.1. Research cruises by year, month, ship/project identification, cruise designator, region, and associated references for data used for all station maps produced for data related to Fig. B3.1. KEY: AO=Arctic Ocean, AOS94=Arctic Ocean Section1994, BERPAC=Joint US-USSR Bering & Chukchi Seas Expeditions, BEST=Bering Sea Ecosystem Study, BS=Beaufort Sea, BSEO=Bering Strait Environmental Observatory, CS=Chukchi Sea, CSESP=Chukchi Sea Environmental Studies Program, ESS=East Siberian Sea, ISHTAR=Inner Shelf Transfer and Recycling project, MV=Marine Vessel, Norseman II, NBS=Northern Bering Sea, RUSALCA=Russian-American Long-term Census of Marine Life, SBI=Shelf-Basin Interactions, SHELL=Shell Oil, SLIPP=St. Lawrence Island Polynya project, USCG=US Coast Guard, USCGC=USCG Cutter, RV=Research Vessel. Also, for data archives: [1]CITAO, Chemical and Isotopic Tracers from the Arctic Ocean, http://data.eol.ucar.edu/codiac/dss/id=106.ARCSS079; [2]PacMARS data archive, http://pacmars.eol.ucar.edu; [3]SBI, http://www.eol.ucar.edu/projects/sbi/; [4]BEST, https://www.eol.ucar.edu/projects/best/; [5]COMIDA CAB, http://www.comidacab.org/; [6]COMIDA Hanna Shoal (HS), http://www.comidacab.org/hannashoal/index.html; [7]CSESP, http://www.fairweatherscience.com.

Year	Month	Ship	Cruises	Region	References; Data archives
1970-1974	July-Sept.	Jan-Feb 1970 USCGC Northwind, Mar-April 1971 USCGC Glacier, Feb-Mar 1972 USCGC Burton Island , July-Sept. 1973 RV Acona & RV Alpha Helix; June-July 1974 RV Alpha Helix	Stoker70-74	NBS, CS	Stoker 1978, 1981; [3]SBI
1976	summer	RV Miller Freeman	FN762	NBS	Feder and Jewett 1978, Feder et al. 2006; [3]SBI
1985	July-Aug.	RV Alpha Helix RV Alpha Helix	HX073, HX074	NBS, CS	Grebmeier et al. 1988, 1989, Grebmeier and McRoy 1989; [3]SBI
1986	July-Sept.	RV Alpha Helix RV Oceanographer RV Oceanographer	HX085 OC862 OC863	NBS, CS	Grebmeier et al. 1988, 1989, Feder et al., 1994a, 2006; [3]SBI
1987	summer	RV Surveyor RV Surveyor	NO871 SU872	CS	Feder et al. 1991a, 2006; [3]SBI
1988	Aug.-Sept.	MV Akademik Korolev (BERPAC-1988)	AK47	NBS, CS	Cooper et al. 2002; Grebmeier et al. 2006a; [1]CITAO, [3]SBI
1990	June	RV Alpha Helix (SLIPP- 90)	HX139	NBS	Grebmeier et al. 1995, Cooper et al., 2002; * [1]CITAO; [3]SBI
1992	Aug.-Sept.	RV Alpha Helix	HX165	CS, BS	Cooper et al. 1998; [1]CITAO
1993	June	RV Alpha Helix (SLIPP-93)	HX171	BS	Cooper et al. 1998, 2002; [1]CITAO; [3]SBI
1993	Aug.	USCGC Polar Star	Polar Star93	CS, AO	Cooper et al. 1998; [1]CITAO
1993	Aug.-Sept.	MV OKEAN (BERPAC-1993)	Okean93	NBS, CS	Cooper et al. 1998, 2002, Grebmeier and Dunton 2000, Grebmeier et al. 2006a; [1]CITAO; [3]SBI
1994	May-June	RV Alpha Helix HX 177 (SLIPP-94)	HX177	NBS	Cooper et al. 1998, 2002; Grebmeier and Dunton 2000; *[1]CITAO; [3]SBI
1995	Aug.	RV Alpha Helix	HX189	CS, ESS	Grebmeier and Barry 2007; [1]CITAO; [3]SBI

Table B3.1 Research cruises by year, month, ship/project identification, cruise designator, region, and associated references for data used for all station maps produced for data related to Fig. B3.1. (cont).

Year	**Month**	**Ship**	**Cruises**	**Region**	**References; Data archives**
1998	July	CCGS Sir Wilfrid Laurier (BSEO-98)	SWL1998	NBS, CS	Grebmeier et al. 2006a; [2]PacMARS
1998	Aug.	RV Alpha Helix (SLIPP-98)	HX214	NBS	Cooper et al. 2002; [1]CITAO
1999	April	USCGC Polar Sea (SLIPP-99/spring)	Polar Sea99	NBS	Cooper et al. 2002; [1]CITAO
1999	July	CCGC Sir Wilfrid Laurier (BSEO-99)	SWL1999	NBS, CS	Grebmeier et al. 2006a; [2]PacMARS
1999	Aug.	RV Alpha Helix (SLIPP-99/summer)	HX224	NBS	Cooper et al. 2002
2000	July	CCGS Sir Wilfrid Laurier (BSEO-00)	SWL2000	NBS, CS, BS	Grebmeier and Barry 2007, Grebmeier et al. 2006a; [2]PacMARS
2001	March-April	USCGC Polar Star (SLIPP-01)	Polar Star01	NBS	Simpkins et al. 2003; [2]PacMARS
2001	July	CCGS Sir Wilfrid Laurier (BSEO-01)	SWL 2001	NBS, CS	Grebmeier and Barry 2007, Grebmeier et al. 2006a; [2]PacMARS
2002	May-June	USCGC Healy (SBI-02/spring)	HLY0201	CS, BS, AO	Cooper et al. 2005b, Grebmeier et al. 2006a, Grebmeier and Barry 2007; [3]SBI
2002	July-Aug. July	USCGC Healy (SBI-02) CCGS Sir Wilfrid Laurier (BSEO-02)	HLY0203 SWL 2002	CS, BS, AO NBS, CS	Cooper et al. 2005b, Grebmeier and Barry 2007, Grebmeier et al. 2006a; [2]PacMARS, [3]SBI,
2003	July	CCGS Sir Wilfrid Laurier (BSEO-03)	SWL 2003	NBS, CS	Grebmeier and Barry 2007, Grebmeier et al. 2006a; [2]PacMARS
2004	May-June July July-Aug. July-Aug.	USCGC Healy (SBI-04) CCGS Sir Wilfrid Laurier (BSEO-04) USCGC Healy (SBI-04) RV Khromov	HLY0402 SWL 2004 HLY0403 RUSALCA04	CS, BS, Arctic Ocean NBS, CS CS, BS, AO CS	Grebmeier and Barry, 2007, Grebmeier et al. 2006a; [2]PacMARS, [3]SBI, [4]BEST [2]PacMARS
2005	July	CCGS Sir Wilfrid Laurier	SWL2005	NBS, CS	[2]PacMARS
2006	May-June July	USCGC Healy CCGS Sir Wilfrid Laurier	HLY0601 SWL2006	CS NBS, CS	Cooper et al. 2012; [4]BEST [2]PacMARS,
2007	May-June July	USCGC Healy CCGS Sir Wilfrid Laurier	HLY0702 SWL2007	NBS NBS, CS	Cooper et al. 2012; [4]BEST [2]PacMARS
2008	Mar-April July Aug-Sept	USCGC Healy CCGS Sir Wilfrid Laurier RV Norseman II	HLY0801 SWL2008 SHELL08	NBS NBS, CS CS	Cooper et al. 2013, [4]BEST [2]PacMARS [7]CSESP

Table B3.1 Research cruises by year, month, ship/project identification, cruise designator, region, and associated references for data used for all station maps produced for data related to Fig. B3.1. (cont).

Year	Month	Ship	Cruises	Region	References; Data archives
2009	Mar-April	USCGC Healy	HLY0901	NBS, CS	Cooper et al. 2013; [4]BEST
	Aug-Sept	COMIDA09	RV Alpha Helix	NBS, CS CS, ESS	Grebmeier 2012; [5]COMIDA CAB
	Aug-Sept	RUSALCA09	RV Khromov	CS	Grebmeier 2012; [2]PacMARS
	Aug-Sept	RV Westward Wind	CSESP09		[7]CSESP, Blanchard et al. 2013
2010	Mar-April	USCGC Polar Sea	PSea2010	NBS	Cooper et al. 2013, [4]BEST
	July	CCGS Sir Wilfrid Laurier	SWL2010	NBS, CS	[2]PacMARS
	Aug-Sept	RV Moana Wave	COMIDA10	CS	[5]COMIDA CAB
	Aug-Sept	RV Westward Wind	CSESP	CS	[7]CSESP, Blanchard et al. 2013
2011	July	CCGS Sir Wilfrid Laurier	SWL11	NBS, CS	Grebmeier 2012, [2]PacMARS [6]COMIDA HS
	Aug-Sept	RV Westward Wind	CSESP11	CS	[7]CSESP
2012	July	CCGS Sir Wilfrid Laurier	SWL12	NBS, CS	Grebmeier 2012, [2]PacMARS
	Aug-Sept	USCGC Healy 1201	COMIDA12	CS	[6]COMIDA HS
	Aug	RV Westward Wind	CSESP12	CS	[7]CSESP

One other consideration for determining which data we would compare was the methodology for converting to biomass from preserved macrofauna. We present here infaunal benthic biomass data as both formalin-preserved wet weight and as carbon dry weight values, the latter obtained with carbon conversion values determined by Stoker (1978) and also used by Grebmeier et al. (1989). This conversion allows removal of heavy carbonate test values that can bias results. These biomass measurement protocols have been widely applied for benthic populations in the Bering and Chukchi Seas (Feder et al. 1994a, 2006, Stoker, 1978, 1981, Grebmeier 1993, Grebmeier et al. 1988, 1995, Grebmeier and Cooper 1995, Grebmeier and Dunton 2000, Simpkins et al. 2003, Blanchard et al. 2013). Due to the importance of benthic food webs in the region, we use spatial patterns in benthic biomass and community structure as indicators of focused organic carbon deposition and recycling sites based on composite, averaged data.

Our goal was to prepare “all-station” files for four decades (1973-2012) of benthic macroinfaunal data, including abundance, g wet weight and gC biomass, with the gC biomass displayed on the EOL web-based Mapserver interface using the geographically referenced data Shapefiles, which are compatible with commercial geographical information system (GIS) software, such as that marketed by ESRI (Redlands, California). We also prepared sediment parameter data including SCOC as an indicator of carbon export to the benthos, sediment grain size, organic carbon content and sediment chlorophyll a data following methods outlined in Grebmeier et al. (2006a) and Cooper et al. (2013). We also provided available integrated chlorophyll a and bottom water nutrient data for benthic stations, when available in order to evaluated water mass type in relation to benthic population parameters. Newly available hydrographic data files are also provided for the US-Canada CCGS Sir Wilfrid Laurier cruises from 2000-2012 listed in Table B3.1. Full details on methodologies are provided in the metafile documents and readme files associated with these data files available from the EOL PacMARS website

Spatial analysis of data was accomplished using a GIS (ArcGIS; ESRI ArcInfo versions 10.1; http://www.esri.com) that includes modeling tools to convert sampled field data into continuous maps. These procedures allowed us to obtain a more synoptic view of patterns over the large sampling area. Our spatial analyses were created by first loading measured, averaged point data for a specific parameter into a geodatabase in ArcCatalog software, creating a feature class. A map template was then opened in

ArcMap, and the feature class data were added to the map via an open Geostatistical Analyst layer. The map layer to be analyzed with the geostatistical analyst subroutine was then highlighted and the ESRI's Geostatistical Wizard software launched. The input data for the specified parameter were then chosen and the attribute to be interpolated selected. Inverse Distance Weighting is the interpolation method that we used. It is a deterministic technique using surrounding measurements to calculate the interpolated surface, and sample data closest to the unmeasured areas contribute proportionally more to the interpolation than sample data located further away. All data points are, however, included in the interpolation without statistical manipulation of the data beyond the default settings of the software. The interpolated layer was then created, a scale selected to best illustrate the data, with the subsequent map exported and saved using Adobe Illustrator (Adobe Systems, Inc.; http://www.adobe.com). Additional details on the methodology for generating the maps are provided in Grebmeier et al (2006a) and Pirtle-Levy (2006).

B4. Epifauna

In the Pacific Arctic, more trawl surveys than photographic surveys have been conducted to date (Table B4.1). Variable gear type for collections include dredges, otter and beam trawls, with variable mesh type (Table B4.1). Epifauna cannot be quantified adequately from van Veen grabs or cores because densities are too low and patchy. In the PacMARS area, epifauna is typically dominated by echinoderms and arthropods in biomass, and within those phyla brittle stars and decapod crustaceans prevail (Fig. B4.1; Feder et al. 2006, Bluhm et al. 2009b, Rand and Logerwell 2011, Blanchard et al. 2013). Phyla with highest species richness include molluscs, in particular gastropods, as well as arthropods and echinoderms. Taxa that require attachment to hard surfaces such as ascidians, bryozoans, hydroids and sponges are found in the comparatively limited areas in the PacMARS region with coarse substrate, for example within Bering Strait, coastal areas near Point Hope and the centers of Herald and Barrow Canyons.

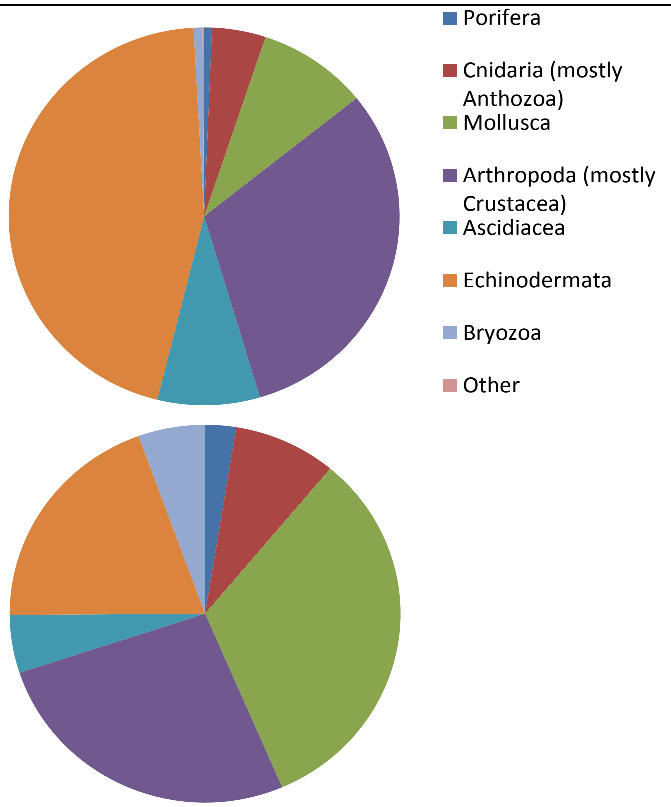


Figure B4.1 Taxonomic composition of epifauna from trawl hauls taken across the Chukchi Sea between 2004 (top pie chart) and 2008 (bottom pie chart; modified from Bluhm et al. 2009b).

Table B4.1 Overview of survey effort of epifaunal invertebrates from trawl hauls and photographic surveys from 1971-2012, sorted chronologically. For most cruises, fish data also exist. Abbreviations for regions: BS-Beaufort Sea, CB-Canada Basin, CS-Chukchi Sea, HS-Hanna Shoal, NBS-northern Bering Sea, NE-northeastern, NS-Norton Sound, S-southern. Abbreviations for gear types: D-dredge, EOT-Eastern Otter trawl, OT-Otter trawl, PSBT-plumb-staff beam trawl, S-still images, ST-Shrimp trawl, V-video. SyT-Synthesis table in PacMARS portal. Data used in figures C4.1-4.4.

Cruise/ Project	Month / Year	Depth range (m)	Region	N° stn	Gear	Mesh size net mm	Mesh size cod end mm	Data archive / contact	Comments
WEBSEC	1972	27-721	US BS	21	ST	13	13	http://pacmars.eol.ucar.edu/ Bluhm, Carey, Schonberg	total haul counts / weights only
FN762	Sept 1976	15-64	S CS	69	EOT	88.9	38.1	http://www.arcodiv.org/Database/Benthos_datasets.html, Blanchard, Feder	
NS Red King crab survey	Jul-Sept 1976-2006	2-61	NBS NS	varies among years	EOT	89	32	www.nprb.org, NMFS /ADFG	biomass data, taxon count for 2006 in SynT
USCGC Glacier OCSEAP	Aug-Sept 1977	40-400	US BS	34	OT	32	6	BOEM Frost/ Llowry, Bluhm	Dominant 40 taxa quantitative, other p/a
Ocean Hope III	Aug-Sept 1990	14-54	NE CS	48 (2 hauls p. stn.)	EOT	89	33	AFSC RACE data base Barber	not yet in SyT
Polar Sea	June 1998	29-212	NE CS	11 (2 for dredge)	V, D	n/a	n/a	Unknown Ambrose	abundances only for echino-derms
Hidden Ocean	Aug/ Sept 2002July 2005	800-3843	CB	4, 6	S/V	n/a	n/a	http://www.arcodiv.org/Database/Benthos_datasets.html McDonald, Bluhm, Iken	video from 2005 not analyzed
RUSALCA	Aug 2004 Sept 2009 & 2012	34-101	US-Russian CS	15, 15, 17	PSBT	7	4	2004: AOOS (to be public soon) Bluhm, Iken	2012 data not in synthesis table yet
HLY0601	May-Jun 2006	27-102	NBS	60	OT	37	4	Ongoing graduate student thesis Lovvorn	taxon count only in synthesis table
Oscar Dyson	Sept 2007	31-52	US CS	7	PSBT	7	4	AOOS Bluhm, Iken	to be public soon

Table B4.1 Overview of survey effort of epifaunal invertebrates from trawl hauls and photographic surveys from 1971-2012, sorted chronologicall (cont.)

Cruise/ Project	Month / Year	Depth range (m)	Region	N° stn	Gear	Mesh size net mm	Mesh size cod end mm	Data archive / contact	Comments
Oshoru Maru IPY	Aug 2007 July 2008	26-51	US CS	6, 15	PSB T	7	4	AOOS Bluhm, Iken	to be public soon
BEST HLY0801, HLY0802	Mar-May 2008	<150	NBS	51	V	n/a	n/a	NPRB Grebmeier, Cooper	not yet in synthesis table
CSESP	Aug 2008 Sept 20092012	33-45	NE CS	22, 22, 38	PSB T	7	4	AOOS Blanchard	
Beaufort Ocean Explorer	Aug 2008	44-470	W US BS	22	EOT	38 / 89	38 / 89	BOEM, AFSC RACE data base Logerwell, Bluhm	slope stations: finer mesh
BeauFish	Aug 2011	10-220	US BS	83	PSB T	7	4	in progress Konar, Ravelo	Ongoing thesis project
COMIDA-CAB	Jul-Aug 20092010	25-130	NE CS	30, 23	PSB T	7	4	http://www.nodc.noaa.gov/cgi-bin/OAS/prd/accession/95566 , Konar, Ravelo	publication in recent special issue
AKMAP	Aug/ Sep 2010 Sept 2011	10-110	NE CS, near-shore	30, 30	PSB T, OT	7, 38	4, 19	in progress Jewett, Dasher	not yet in SyT
AFSC RACE survey	Jun-Aug 1985 19881991 2010	11-78	NBS	142 (2010)	EOT	89	89	http://www.afsc.noaa.gov/RACE/groundfish/survey_data/data.htm Lauth	not yet in SyT
Arctic Eis	Aug/ Sept 2012	12-90	US CS	86	PSB T, EOT	89, 7	89, 4	in progress Lauth, Norcross, Mueter	not available for SyT yet
US-Can Trans-boun-dary	Sept 2012 Aug 20132014	17-1000	US BS, W Can. BS	18	PSB T	7	4	in progress Bluhm, Iken	not available for SyT yet
COMIDA-Hanna Shoal	2012, 2013	41-65	HS, CS	21	PSB T	7	4	in progress Konar	not available for SyT yet

B5. Stable Isotopes and Food web Structure

B5.1 Stable isotope inventory

A total of 7618 measurements of stable carbon and nitrogen isotope ratios were compiled to explore the range, distribution, and functional role of different lower trophic organisms and to investigate trophic structure and fate of organic matter within the Pacific-influenced coastal shelf ecosystem of the Arctic Ocean (Fig. B5.1). These data represent a synthesis of carbon and nitrogen stable isotope data from several studies collected into a single GIS feature class. Data are expressed as $\delta^{13}C$ and $\delta^{15}N$ values. Metadata including the names of the original data collectors or compilers are included as attributes of the feature class in the archived database.

Approximately 4160 samples, collected over a period of three decades, from the early 1980s to present, were analyzed for stable carbon isotopic analysis (Fig. B5.1). Out of this total, 3458 samples were also analyzed for $\delta^{15}N$. The data sources reflect contributions from a variety of investigations over the years (Table B5.1), and are arguably unprecedented in scope and detail for any region of the world's ocean.

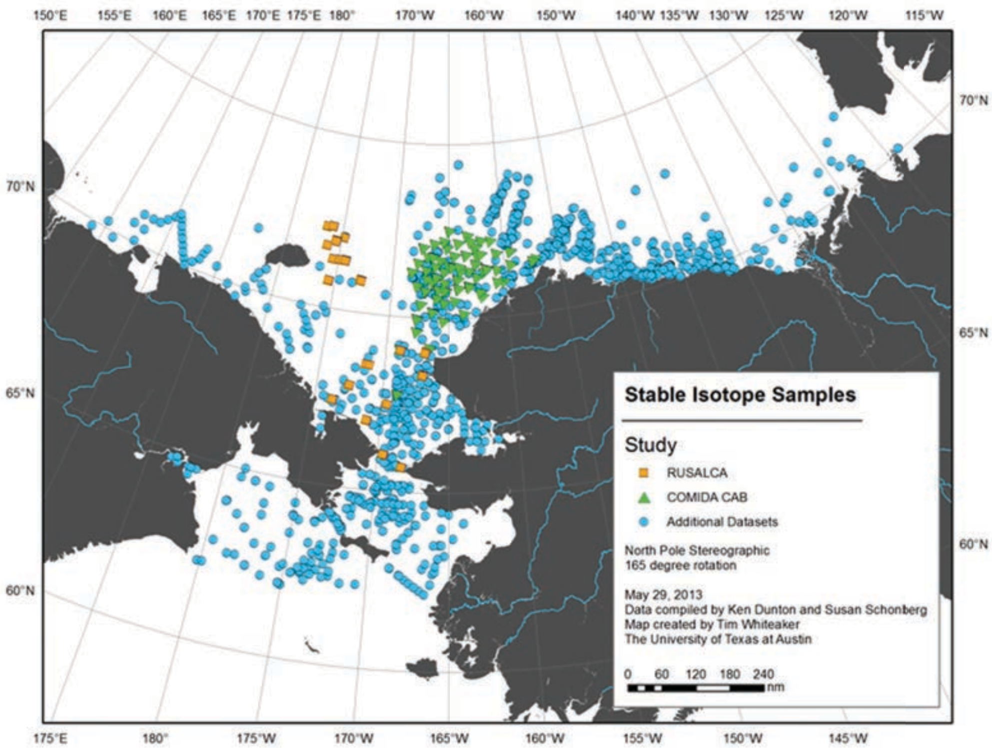


Fig. B5.1 The location of samples analyzed for stable carbon and nitrogen isotopic analysis in PacMARS study area in the western arctic. The majority of field collections program samples were collected in the northern Bering, eastern Siberian, Chukchi, and Beaufort Seas.

Table B5.1. The sources of data, number of samples, and data types of the isotopic data in this report.

DATA SOURCE CRUISE ID	No. Records	Data Types
Aumack SBI RV Palmer summer 2003	57	pelagic, POM
BERPAC 1993	16	pelagic
Casey Boulder Patch, Beaufort Sea	35	benthic, pelagic
Cooper HX189	55	sediment
Cooper NOAA	31	sediment
Cooper RUSALCA 2004	13	sediment
Cooper Slip99 1999	24	sediment

DATA SOURCE CRUISE ID	No. Records	Data Types
Dunton Beaufort Sea 2003	2	sediment, POM
Dunton Boulder Patch, Prudhoe Bay 1980	47	benthic
Dunton Boulder Patch, Prudhoe Bay 2006	9	benthic, POM
Dunton Camden Bay 2007	4	benthic, pelagic
Dunton COMIDA RV Alpha Helix 2009	398	benthic, pelagic, POM, phytoplankon, sediments
Dunton COMIDA RV Moana Wave 2010	144	benthic, pelagic, POM, phytoplankon, sediments
Dunton Eastern Beaufort 2003	9	pelagic, POM, sediment
Dunton Eastern Beaufort 2007	5	benthic, pelagic
Dunton Eastern Beaufort lagoons 2004	82	benthic, pelagic, POM, phytoplankon, sediments
Dunton Eastern Beaufort lagoons 2007	64	benthic, pelagic, POM, phytoplankon, sediments terrestrial
Dunton Eastern Beaufort lagoons 2008	1	benthic
Dunton Harrison Bay, Beaufort Sea 2010	87	benthic, pelagic, POM, phytoplankon, sediments
Dunton Prudhoe Bay	2	benthic, pelagic
Dunton Prudhoe Bay 1980	17	benthic, pelagic
Dunton Prudhoe Bay 2004	2	benthic, pelagic
Dunton Prudhoe Bay 2006	1	pelagic
Dunton RV Discoverer	18	benthic
Dunton Shell Camden Bay 2008	403	benthic, pelagic, POM, phytoplankon, sediments
Feder SE Chukchi 1987	155	benthic, pelagic
Golikov Russia 1989	12	benthic
Grebmeier RV Laurier 2000	97	benthic
Horner RV Glacier 1997	28	pelagic
Iken Rusalca 2004	207	benthic
Iken, Bluhm Rusalca 2004	363	benthic, pelagic, POM
McTigue Shell Chukchi 2009	187	benthic, pelagic, POM, sediments
McTigue Shell Chukchi 2010	124	benthic, pelagic, POM, phytoplankon, sediments
Naidu	218	sediments
Naidu published paper	111	sediments
NP 1994	1	pelagic
Polar Star 1986	11	pelagic
Polar Star Beaufort Sea 1986	58	benthic, pelagic
RV Akademic Korolev 1988	65	pelagic
RV Alpha Helix 1987	19	pelagic
RV Annika Marie 1985	3	pelagic
RV Annika Marie 1986	17	pelagic
RV Sequel 1985	1	pelagic
RV Surveyor 1987	19	pelagic
RV Surveyor 1988	30	pelagic
RV Surveyor 1989	29	pelagic
RV Surveyor 1990	32	pelagic
RV Surveyor 1991	29	pelagic
RV Thompson 1987	11	pelagic
RV Thompson 1988	28	pelagic
RV Tully 1986	6	pelagic
Schonberg SBI RV Healy spring 2002	222	benthic, pelagic, POM
Schonberg SBI RV Healy spring 2004	110	benthic, pelagic, POM
Schonberg SBI RV Healy summer 2002	239	benthic, pelagic, POM
Schonberg SBI RV Healy summer 2004	201	benthic, pelagic, POM

B5.2 Trophic level determinations

Trophic levels for all biota were determined from isotopic values following the trophic enrichment equation of Iken et al. (2010):

$$TL\ (POM) = (\delta^{15}N_{consumer} - \delta^{15}N_{POM})/3.4 + 1$$

where 3.4 is the average ‰ enrichment in $\delta^{15}N$ between successive trophic levels (TL) using POM as the ultimate trophic carbon source. We recognize in using 3.4‰ that there is some variation in the appropriate enrichment per trophic level in different ecosystems, including the ecosystem studied here. For example, in the Antarctic Peninsula, Dunton (2001) used a value of 3.2‰ per trophic level, which is comparable tovalues of 3.3‰ applied by Wada et al. (1987) to the Southern Ocean and Rau et al. (1992) in the northeast Atlantic. In the Alaskan Arctic, Iken et al. (2010) used a 3.4‰ enrichment based on the extensive reviews of the topic by Vander Zanden and Rasmussen (2001) and Post (2002), which identified 3.4‰ as an average isotopic fractionation for aquatic consumers. We used an average POM value of 6.06‰ based on 242 independent samples collected throughout the entire study area.

B6. Chemical Contaminants

Data for trace metals, polycyclic aromatic hydrocarbons (PAH) and petroleum hydrocarbons (HC) in surface sediments have been placed in the PacMARS data base for 218 stations in the Chukchi Sea (Fig. B6.1; Naidu et al. 1997, Valette-Silver et al. 1999, Neff et al. 2009, Trefry et al. 2013, Harvey et al. 2013, Astakhov et al. 2013a,b) and 473 stations in the Beaufort Sea (Figs. B6.1 and B6.2; Boehm et al. 1990, Crecelius et al. 1991, Valette-Silver et al. 1999, Trefry et al. 2003, Brown et al. 2004, 2010, Belicka et al. 2009, Naidu et al. 2012, Trefry et al. 2013). Table B6.1 summarizes data sources for contaminants in sediments and benthic biota. Sediments were collected during the period of 1977-2010; however, >80% of the samples were collected from 1999 and 2010. Data for contaminants in age-dated sediment cores from the Chukchi Sea (n = 230 samples in 16 cores) and the Beaufort Sea (n = 230 samples in 25 cores) also have been included in the PacMARS database (Neff et al. 2009, Trefry et al. 2003, 2010, 2013, 2014, Brown et al. 2004, 2010, Belicka et al. 2009, Naidu et al. 2012, Harvey et al. 2014). Data collected by the oil industry, including the CSESP, are also included in our database (e.g., Neff et al., 2009). All data selected for inclusion in this synthesis have met QA/QC requirements that include analysis of replicate samples for precision determination and certified samples for accuracy checks.

The following metals are included in the data base: Ag, Al, As, Ba, Be, Cd, Co, Cr, Cu, Fe, total Hg, Methyl Hg, Mn, Pb, Sb, Se, Sn, Tl, V and Zn. Data for organic substances in sediments are predominantly for petroleum hydrocarbons (n-alkanes including pristine and phytane, total petroleum hydrocarbons, saturated hydrocarbons) and PAH (42 parent compounds plus eight alkyl isomers). Very few data are available for chlorinated hydrocarbons, including pesticides in these marine sediments.

Data for metals and PAH in sediments from the Beaufort and Chukchi seas are primarily from studies sponsored by BOEM that are related to offshore oil and gas exploration and production (Sweeney and Naidu 1989, Crecelius et al. 1991, Naidu et al. 1997, Trefry et al. 2003, 2013, 2014, Brown et al. 2004, 2010, Boehm et al. 1990, Neff et al. 2009, Naidu et al. 2012, Harvey et al., 2013). In Section C6, we combine the various data sets available to facilitate an overall assessment of sediment contamination in the PacMARS study area.

Data for metals and organic substances in biota have come from studies of benthic biota and sediment contaminants related to offshore oil and gas activities and from assessments of contaminants in fish, marine mammals and birds by state and federal agencies. In the first case, data for metals, hydrocarbons and PAH in benthic biota are linked with results for sediments (Boehm et al. 1990, Valette-Silver et al. 1999, Brown et al. 2004, Neff et al. 2009, Neff and Durell 2012, Harvey et al. 2014, Fox et al. 2014). In the second case, data for some metals, especially methylmercury (MeHg), and halogenated compounds (e.g., PCBs and pesticides) have been collected for seals, walrus, polar bears, whales and selected birds

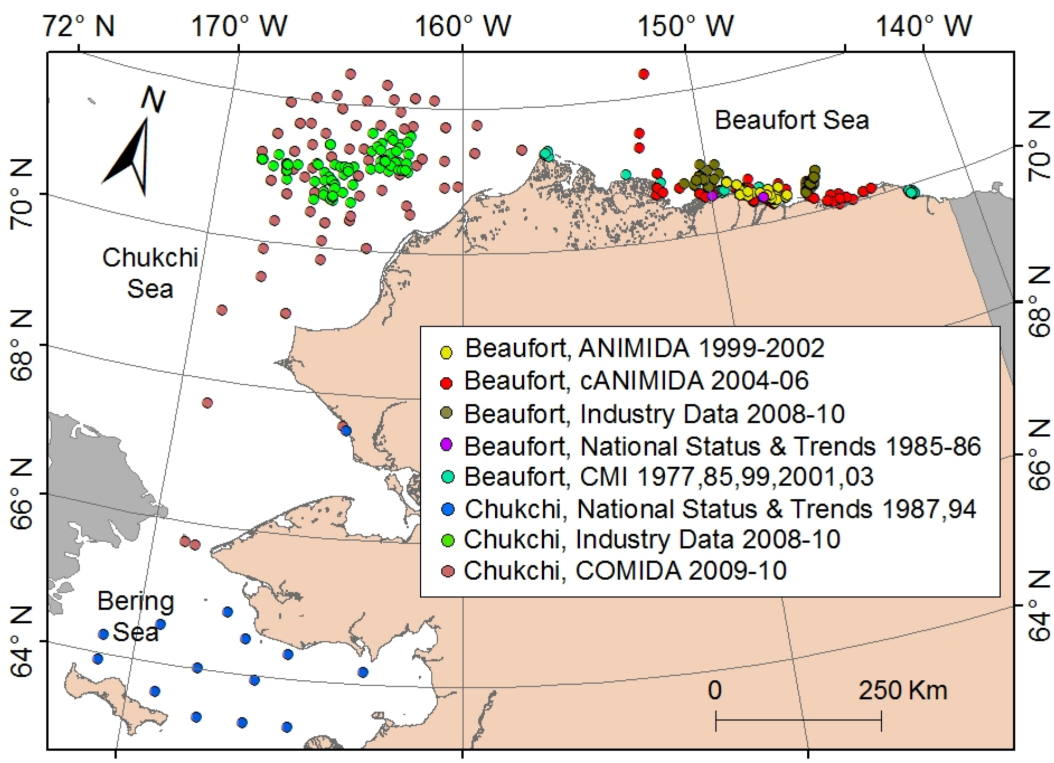


Figure B6.1 Sediment sampling locations for contaminants in the PacMARS study area.

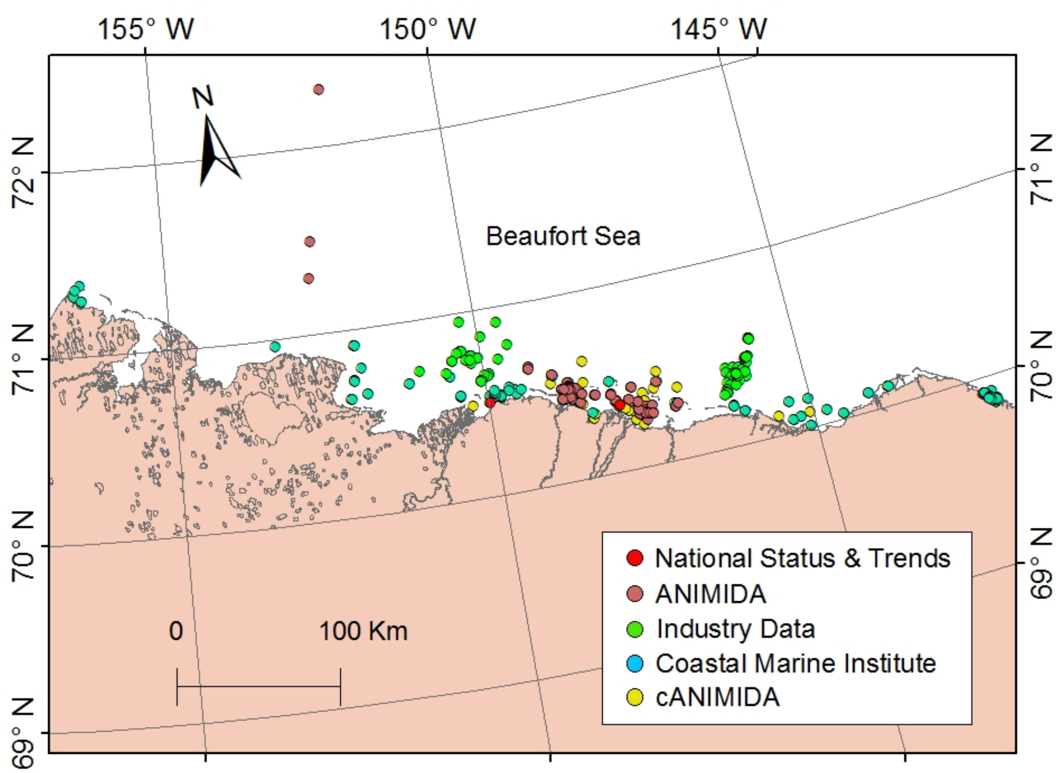


Figure B6.2 Sediment sampling locations for contaminants in the coastal Beaufort Sea.

Table B6.1. Data sources for contaminants in sediments and biota.

Data Source	Sample Location	Sample Type	Number of samples	Data type
Natl. Status & Trends (1985-1994)	Beaufort, Chukchi	Sediment	18 18	Metals PAH, HC
CMI, UAF (1977-2003)	Beaufort, Chukchi	Sediment	105 42	Metals PAH, HC
ANIMIDA (1999-2002)	Beaufort	Sediment	130 129	Metals PAH, HC
ANIMIDA (199-2002)	Beaufort	Benthic biota and fish	38 38	Metals PAH, HC
cANIMIDA (2004-2006)	Beaufort	Sediment	38 38	Metals PAH, HC
cANIMIDA (2004-2006)	Beaufort	Benthic biota and fish	38 38	Metals PAH, HC
CSESP & Industry data (2008-2010)	Beaufort, Chukchi	Sediment	204 213	Metals PAH, HC
CSESP & Industry data (2008-2010)	Beaufort, Chukchi	Benthic biota	37 42	Metals PAH, HC
COMIDA (2009-2010)	Chukchi	Sediment	86 52	Metals PAH, HC
COMIDA (2009-2010)	Chukchi	Benthic biota	47	Metals
Russian Data (2006-2009)	Chukchi	Sediment	166	Metals

(e.g., Atwell et al. 1998, Norstrom et al. 1998, O'Hara et al. 1999, Hoekstra et al. 2003, Kannan et al. 2005, 2007, Smithwick et al. 2005, Muir et al. 2006, Michelutti et al. 2009, McKinney et al. 2011, AMAP 2012). Little or no supporting environmental data (e.g., chemicals in soils, sediment and water) are included in these studies of highly mobile species. The data available from the Canadian and Norwegian Arctic, as well as other Arctic areas is large relative to that available for the Chukchi Sea and Alaskan Beaufort Sea and are used in this synthesis as a reference point for different contaminants, as needed. We have worked to combine data for biota from the two types of studies by keying on temporal trends and the degree of bioaccumulation and biomagnification. Only the references for data sources for biota are listed here due to the diverse list of species and tissues analyzed; more details follow in Section 6C.

Overall, the synthesis for chemical contaminants includes the following three components: (1) a data base for contaminants in sediment and biota, (2) an overview synthesis of the data, and (3) a synthesis manuscript in preparation.

B7. Upper Trophic Levels

B7.1 Marine Mammals, seabirds and fish (Federal, State and Local agencies)

Methods for sample collections by USGS walrus, USFWS seabird, NOAA/BOEM marine mammal projects, NOAA and UAF fisheries, and ADF&G upper tropic level survey programs, are outlined in the websites listed in the introduction section and in Appendix G1.

B7.2. Demersal fishes (UAF)

Estimates are now needed for the recently implemented Arctic Fisheries Management Plan (AFMP 2009). Small-mesh nets, usually associated with smaller gear size, can be deployed from most research vessels operating in the area, and efficiently catch the generally small Arctic demersal fishes and a larger range of epibenthic invertebrates (e.g. Norcross et al. 2010, Blanchard et al. 2013). Comparisons of the large-mesh Eastern Otter Trawl and the small-mesh beam trawl are underway in the Chukchi Sea based on samples from the Arctic Eis survey (see Table B4.1). In a recent CMI-funded project, Dr. Brenda Norcross and collaborators digitized (where necessary), integrated and analyzed data on demersal fish distribution and species richness from 501 bottom hauls at 406 stations during 15 cruises conducted during 13 years (mostly in Aug and Sept) between 1959 to 2008 in the Chukchi Sea (Fig. B7.1; Norcross et al. 2013a). As is the case for the epibenthic invertebrates from trawl hauls (Table B4.1), trawl gear used differed with respect to mesh size, gear size, and trawl duration which made data integration challenging. To reduce bias caused by use of different gear types, integrated historic and recent (2000s) data sets were analyzed on the basis of presence/absence rather than CPUE. Analyzes of more recent data were conducted based on abundance or biomass data (Norcross et al. 2013a, b, Bluhm et al. in prep.). Community analysis was conducted using multivariate approaches (PRIMER v6).

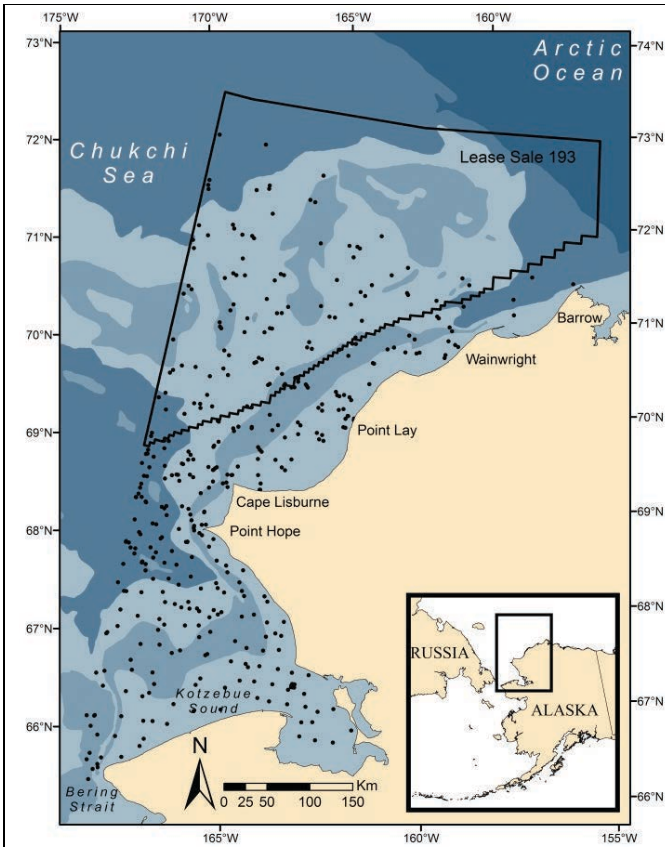


Figure B7.1. Trawl coverage for demerals fishes for the Chukchi Sea (1959-2008) considered by Norcross et al. (2013a).

Sampling effort has dramatically increased in the PacMARS area since 2008. Demersal trawl-based fish data from the Chukchi Sea after 2008 have not been published yet, but include at least nine cruises (Table 7.1) that together have covered the entire US and parts of the Russian Chukchi Sea (similar to the coverage in Fig. B7.1). Historic fish data from the Beaufort Sea shelf were compiled in an MMS- funded study led by Dr. E. Logerwell and collaborators (Rand and Logerwell 2010). Recent sampling in the US Beaufort Sea fish survey since the 1970s did not occur until 2008 (Rand et al. 2011), Logerwell et al. 2011, Parker-Stetter et al. 2011). The US Beaufort Sea survey coverage has since been substantially expanded across the entire shelf and parts of the slope (Table B7.1, coverage similar to Fig. B4.1). Trawling has also been conducted in the Canadian Beaufort Sea in recent years (2012/2013 efforts included in Table B7.2.2). In the northern Bering Sea, two surveys have been conducted by NOAA scientists and two were conducted by PacMARS PIs J. Grebmeier and L. Cooper with collaborators (Cui et al. 2009, 2011).

The dominant two types of trawl gear used have included the NOAA AFSC standard trawl survey otter trawl 83-112, and a smaller plumb staff beam trawl (PSBT) (Gunderson and Ellis 1986). Mesh sizes are much smaller in the PSBT (7 mm with 4 mm in the cod end) than the 83-112 (89 mm with 31 mm in the cod end). Trawl durations using the 83-112 often were the standard 30 min also used in the southeastern Bering Sea trawl surveys (e.g., Barber et al. 1997), while the PSBT was typically deployed for 2-5 min at the bottom (Norcross et al. 2010, 2013a,b). A gear comparison of the two trawl types was done for the 2012 Arctic Eis survey (Lauth and Norcross 2013, unpublished draft report).

Table B7.1 Survey effort with demersal fish trawl hauls in the Chukchi and US Beaufort Seas after 2008. Surveys until 2008 were synthesized and data archived by Norcross et al. (2013a) and Logerwell et al. (2010). Project acronyms and details are explained in G7.

Project/cruise	Year(s)	Region	Gear	Contact	References/ data archive
HLY06-01, HLY0702	2006, 2007	Northern Bering Sea	Otter trawl (2006), beam trawl (2007)	Dr. J. Grebmeier	Cui et al. 2009 MEPS 293,147-160
AFSC	2011	Northern Bering Sea	83-112	AFSC	RACE data base
CSESP	2008-2013	Northeastern Chukchi	Plumb staff beam trawl	Dr. B. Norcross, Consulting companies	Data with industry and at AOOS
NMFS	2008	Western Beaufort Sea	83-112 (partly lined)-demersal	E. Logerwell	NOAA
RUSALCA	2009, 2012	Southern Chukchi Sea, Herald Canyon area	Plumb staff beam trawl, otter trawl	Dr. B. Norcross, C. Mecklenburg	Data will be at AOOS
COMIDA-CAB	2009, 2010	Northeastern Chukchi	Plumb staff beam trawl	Dr. B. Norcross Dr. B. Konar	2009: will be at AOOS, 2010 at NODC
AKMAP	2010 2011	Coastal Chukchi Sea	Plumb staff, beam trawl, otter trawl	Dr. B. Norcross	
COMIDA Hanna Shoal	2012, 2013	Hanna Shoal, NE Chukchi	Plumb staff, beam trawl	Dr. B. Konar	
Arctic Eis	2012	US Chukchi Sea	83-112, plumb staff, beam trawl	Dr. R. Lauth / AFSC, Dr. B. Norcross	RACE data base, Axiom workspace
SHELFZ	2013	Northeastern Chukchi	83-112, plumb staff beam trawl	Dr. E. Logerwell	At RACE data base once processed
WWW1004	2010	Camden Bay, Beaufort Sea	Plumb staff beam trawl	Dr. B. Norcross	
BeauFish	2011	US Beaufort Sea shelf	Plumb staff beam trawl, otter trawl	Dr. B. Norcross	Final report near submission
US-Can Transboundary	2012, 2013	Central and eastern Beaufort Sea shelf and slope into Mackenzie Delta	Plumb staff beam trawl, otter trawl (2012)	Dr. B. Norcross	Cruise reports with BOEM
BREA	2012, 2013	Canadian Beaufort Sea, Amundsen Gulf	Canadian beam trawl, otter trawl	Dr. A. Majewski and DFO	Cruise reports with DFO
ACES	2013	Nearshore western Beaufort Sea	Beach seine	Dr. Boswell	

B8. Social Science Synthesis and Community Meetings

B8.1 Studying the human environment

With the marine environment as its focus, the direction of the PacMARS effort conceived broadly as a "social science component" is dedicated to the human element. The International Polar Year 2007-2008 Joint Committee describes this kind of approach as the "'human dimension' paradigm,' which 'assumes the leading role of the physical and natural processes, to which a certain 'human aspect' (or 'dimension') is to be added to produce a more integrative or societal-appropriate view" (Krupnik and Hovelstrud 2011:311). The human dimensions paradigm is an important historical step in bringing social and human sciences into the development of multi-disciplinary research endeavors. With the growing receptiveness toward viewing ecosystems through a lens of social-ecological processes (Berkes and Folke 1998), the human dimensions paradigm is now being succeeded by more integrative approaches.

The 2013 report by the NPRB Social Science Working Group emphasizes that quality social science requires time and sufficient resources (Ouanian et al 2013). Given the complexities of the human condition, social science encompasses a vast diversity of disciplines and subdisciplines. A sole cultural anthropologist on the PacMARS team was tasked with representing the social science perspective, which indubitably would have been enriched with the input of scholars in cultural geography, political science, linguistics, economics, and a number of other disciplines. By contrast, nine specialists, each with a distinct expertise in the zooplankton, benthos, physical oceanography, ocean contaminants, and more collectively represented the "marine science." The history of privileging natural science disciplines (Krupnik and Hovelstrud 2011, Strang 2009) makes the appropriate disciplinary representation of the social sciences crucial in ensuing that collaborative conversations arise from an equal place.

The discussion presented in the Section C8, focusing on the emerging perspectives on the interactions of subsistence and climate change in the coastal Alaskan Arctic, resulted from a review of library and online resources. We became aware of many of these resources thanks to the guidance of our colleagues, including the PacMARS Advisory Committee, and the advice given by community representatives during the meetings held in Savoonga, Gambell, Barrow, Kotzebue, and Nome. The main library research site for this effort was the Alaska and Polar Regions Collection at the University of Alaska Fairbanks. Over the duration of the PacMARS effort, we were turning to representatives of pertinent university-based research programs, indigenous organizations, state and federal agencies, and private consulting firms, specializing in the social sciences research in Arctic Alaska, for updates on the ongoing and completed endeavors.

The component that focuses on the human environment is different from other PacMARS components in its utilization of data products rather than raw data. That is because the curatorship of human subject data is bounded by a different set of principles that those guiding the sharing of data from physical sciences. Researchers working with the human subject data are responsible to protect the participant privacy, intellectual property rights, and information that may be considered sensitive for many different reasons. In the United States, Institutional Review Board typically facilitates the oversight of legal and ethical parameters of working with human subjects. The conditions for usage of data obtained in the course of working with human subjects is stipulated through individual agreements between the investigator and those participating in the research. A protocol in place may prohibit third party access to data altogether, or it may set restrictions against certain type of use (such as destructive analysis, commercial application, politically motivated agenda, etc.). Where sharing of human subjects data is restricted but not prohibited, a third party investigator can enter a permitting process that is to determine whether the intended use is acceptable. This process may involve the permission of both the researcher and the participants, or an entity that represents the participating group, such as the local or tribal government.

The set of principles surrounding the use of human subjects data poses unique curatorial challenges. The challenges of meeting the privacy, sensitivity, and intellectual property concerns are further complicated by the facts that data from the social science disciplines is crucially dependent on context (Cajete 2000, Cruikshank 1998), and may differ greatly in form from the physical science data (Strawhacker et al 2013). Some of these challenges are conflicting with the need for easy mechanisms of accessing research information, stated by Arctic communities, agencies, and other stakeholders (Knapp and Trainor 2013). The PacMARS timeline coincided with several ongoing efforts in the Arctic research community to address proper and effective management of social science data, which are promising in helping the future implementation of interdisciplinary and multi-institutions endeavors (Strawhacker et al 2013).

***B8.2.* Community Meetings**

As part of the PacMARS effort, we held meetings with local community members and representatives during January and February 2013 (Table B8, see Appendix G8). The purpose of these meetings was to inform local residents of the PacMARS goals and solicit their recommendations for future research and community engagement. Members of the PacMARS investigator team and village members attended meetings in Savoonga and Gambell (held at both communities), and a "hub meeting" structure was used in Barrow, Kotzebue, and Nome. The hub meetings were held with the participation of village representatives from outlying villages as well as the hub villages. These representatives were chosen by the tribal government entity in each outlying community and there were also mechanisms in place for representation from the hub communities (Nome, Kotzebue, and Barrow) themselves. Specifically, PI Sheffield sent a written invitation to all tribal council offices in the PacMARS region and contacted with them by telephone in order to answer questions about the project goals and the purpose of the meetings. Community representative travel and local logistics were arranged by Sheffield, Ashjian and Cooper. Other participants in the meeting included representatives from the NPRB, AOOS (Alaska Ocean Observing System), North Slope Borough, Northwest Arctic Borough, and PacMARS PIs Ashjian, Cooper, Grebmeier, Okkonen, Sheffield, and Yamin-Pasternak

Table B8. Date, location and communities served at PacMARS regional community meetings**.**

Date	Meeting Location	Communities Represented
January 28, 2013	Savoonga	Savoonga
January 29, 2013	Gambell	Gambell
February 11, 2013	Barrow	Barrow, Wainwright, Point Lay, Nuiqsut, Kaktovik
February 22, 2013	Kotzebue	Kotzebue, Point Hope (representative unable to attend), Buckland, Kivalina
February 25, 2013	Nome	Nome, Diomede, Wales (no representative attended), King Island (representative unable to attend) Brevig Mission, Teller, Shishmaref

The PacMARS community meeting objectives included:

- To provide an explanation of the PacMARS effort
- To give updates on research in the respective areas
- To discuss marine issues important to the communities including gaps for future study
- To discuss useful ways of communicating science results
- To identify good examples of regional knowledge and western science working together

Comments were collected on community identified marine issues of concern and suggestions for future research needs and communications.

B9. EOL - PacMARS Data Archive: Mapserver and Data Sets

The National Center for Atmospheric Research (NCAR) Earth Observing Laboratory (EOL) was responsible for data management support to PacMARS. This includes the archiving of new PacMARS datasets in EOL, the integration into the Advanced - Cooperative Arctic Data and Information Service

(ACADIS) system, utilization of the EOL GIS Mapserver tool and collaboration with UMCES and the PIs to develop GIS layers as an aid to synthesis. An online PacMARS Data Archive was developed and implemented for the project team and collaborators http://pacmars.eol.ucar.edu.

The overall goal of the data synthesis was to document where relevant data resides, but not to put all data sets into a data archive. The technical staff at EOL and UMCES developed a comprehensive workflow approach (Fig. B9.1) for handling new data, old data needing GIS formatting, and related procedures. A PacMARS data policy was also developed at the start of the project (Appendix G3). As new datasets were identified and/or reformatted they were submitted to the data archive at NCAR/EOL. All submitted data sets are organized with the help of discovery metadata that were accessible and usable by the PacMARS team and are available to the broad scientific community upon completion of the PacMARS project (see Appendix G4). Each data set has also been assigned a doi number (Appendix Table G5.1). EOL set up the web site to supply the links to data sets it archives as well as link to data sets that it does not archive (http://pacmars.eol.ucar.edu/). Links to all datasets related to the project and archiving of new synthesis products developed during the effort are provided. All PacMARS data, metadata and documentation are linked directly into ACADIS and it will be responsible for the long-term stewardship of the data and metadata. Data were restricted to only PacMARS participants as required during the contract period. A data questionnaire was utilized to facilitate the gathering of relevant data and information for PacMARS. Information from the questionnaire resulted in a comprehensive data status table that was used to track the ingestion of datasets, availability of news products (e.g. GIS layers) and other synthesis products (Appendix Table G5.1). A focused data workshop was held in December 2012 to determine data in hand and discuss how to obtain other needed datasets, augment GIS overlay content, discuss synthesis products and tune priorities for the subsequent synthesis activities.

EOL implemented the GIS MapServer capabilities used on several recent field deployments to help the PacMARS team visualize and potentially access available marine ecosystem data, products and other value added content. Collaborators from UMCES and EOL staff prepared multiple standardized format shape GIS files. Other work with project collaborators and consultants provided additional valuable data and information area that were archived and available to the PI team during the synthesis effort. More details on the PacMARS archiving effort, workflow method, and cross-linking of data sets are provided in Appendix G5.

A very worthwhile collaboration with the Alaska Ocean Observing System (AOOS) office and Axiom, Inc. was undertaken to better integrate the new oil industry data from the NE Chukchi Sea that was made available to the PacMARS Project in fall 2012. Axiom provided support to ingest the industry data into the AOOS workspace, generate GIS shapefiles and provide access to them for inclusion in the EOL MapServer. This collaboration with industry via a collaborative agreement with NOAA and facilitated by AOOS is a first for sharing data and fully integrating them into the scientific analysis efforts.

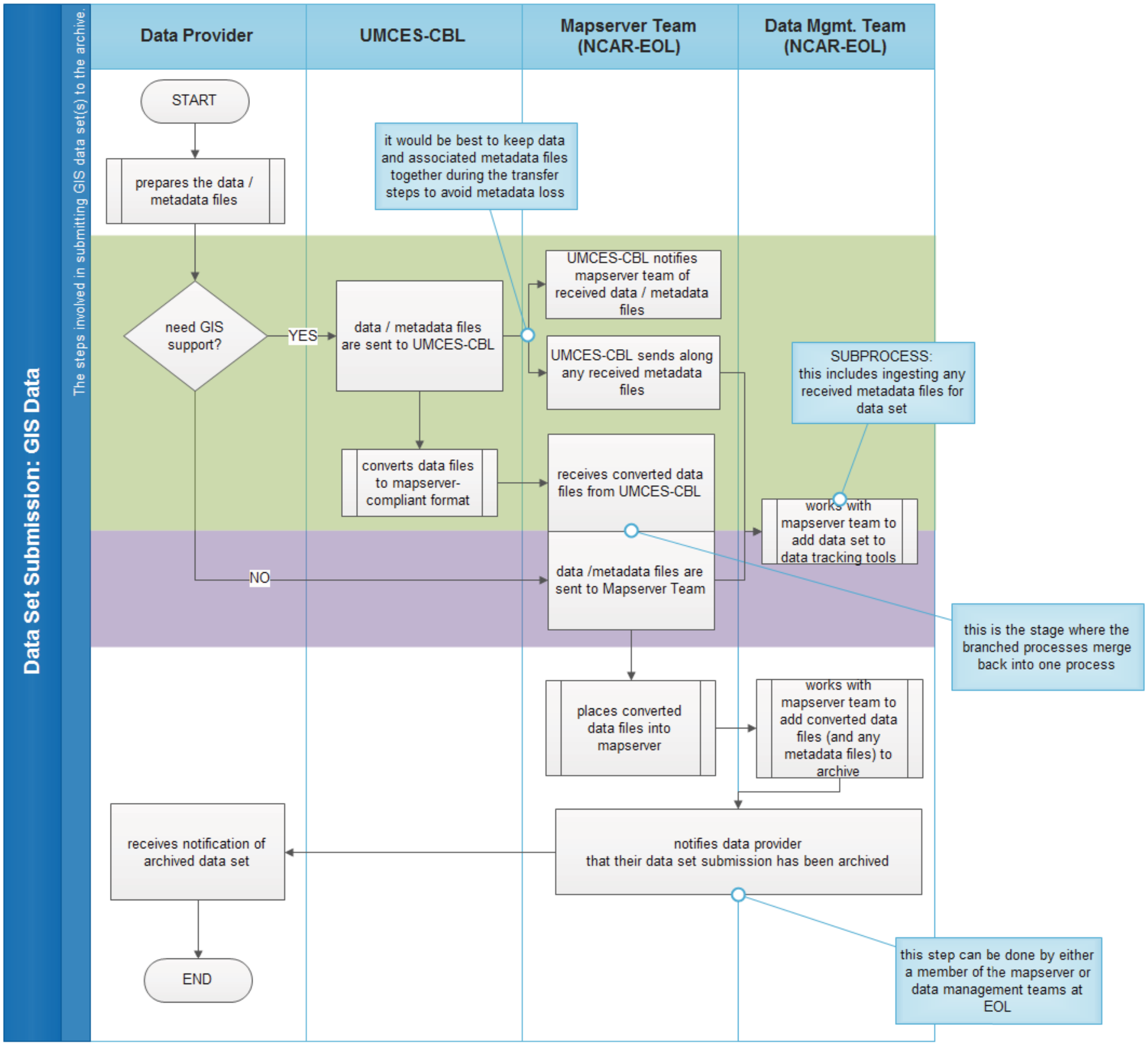


Figure B9.1. Graphical Workflow diagram for PacMARS data submission to GIS Mapserver and data archive at EOL.

C. RESULTS AND DISCUSSION

Preamble

Over the years, there have been a number of multi-and inter-disciplinary projects in the Pacific Arctic region that should be highlighted initially as they contribute seminal data to any ecosystem synthesis of the region. These projects were multidisciplinary and/or interdisciplinary, with recent projects also including social-ecological evaluations. For example, there has been a concerted effort to improve our lower and upper trophic understanding through the BOEM-funded Chukchi Sea Monitoring in Drilling Area (COMIDA) (Chukchi and Benthos (CAB) and Hanna Shoal (HS) projects and the oil and gas industry-supported Chukchi Sea Environmental Studies Program (CSESP) effort in the Chukchi Sea (Day et al. 2014, Dunton et al. 2014). In the Beaufort Sea, BOEM efforts include the "Arctic Nearshore Impact Monitoring in the Development Area (ANIMIDA)" project (1999 - 2002), the "Continuation of the Arctic Nearshore Impact Monitoring in the Development Area (cANIMIDA)" project (2004 - 2007), and the new ANIMIDA III project to extend this monitoring work into Camden Bay (see http://nssi.portal.gina.alaska.edu/catalogs/3097-boem-arctic-nearshore-impact-monitoring-in-deve/). Also many social-ecological efforts are included within BOEM-supported studies, including those tabulated in this section and/or listed in Appendix G1. PacMARS Data Source Table.

Although not all-inclusive, Table C1 provides an overview of selected interdisciplinary projects in the northern Bering, Chukchi and Beaufort seas that contributed knowledge to the PacMARS synthesis effort.

Table C1. Summary of Interdisciplinary Projects in the Northern Bering, Chukchi and Beaufort Seas.

Acronym	Name	Region	Dates	Reference
AIDJEX	Arctic Ice Dynamics Joint Experiment	Beaufort Sea	1972–1976	• Untersteiner, N. 2007. A retrospective, AIDJEX revisited: A look back at the U.S.-Canadian Arctic Ice Dynamics Joint Experiment 1970–78. Arctic 60(3), 327–336.
ANIMIDA and CANIMIDA	Arctic Nearshore Impact Monitoring in Development Area, Phase I and Phase II	Beaufort Sea	1999–2006; 2013	•http://www.alaska.boemre.gov/ess
BERPAC	Long-Term Ecological Research of Marine Ecosystems in the Arctic and Pacific Oceans	Chukchi and Bering Seas, North Pacific Ocean	1977–1997	• Tsyban, A. 1999. Ecological investigations in the Russian Arctic seas: Results and perspectives. Aquatic Conservation: Marine and Freshwater Ecosystems 9, 503–508 • Monographs 1988 and 1993
BEST	Bering Sea Integrated Ecosystem Research Program	Eastern Bering Sea, Northern Bering Sea	2007-2014	• bsierp.nprb.org Deep-Sea Research II, 2011, 2012, 2013, 2014 (three special issues in print, one in preparation; >100 peer reviewed publications)
C3O	Canada's Three Oceans	subarctic Pacific, Bering, Chukchi, Beaufort, Canadian Archipelago,	2007–present	• http://www.dfo-mpo.gc.ca/science/Publications/article/2008/17-06-2008-eng.htm • Carmack, E.C., F.A. McLaughlin, S. Vagle, H. Melling, and W.J. Williams. 2010. Atmosphere-Ocean 48(4), 211–

		Lancaster Sound, BaffinBay, Labrador Sea		224 • J. Geophys Res Special Issue, 2013
CASES	Canadian Arctic Shelf Exchange Study	Beaufort Sea and Amundsen Gulf	2002–2007	Fortier, L., and J.K. Cochran. 2008. Introduction to special section on Annual Cycles on the Arctic Ocean Shelf. Journal of Geophysical Research 113, C03S00, doi:10.1029/2007JC004457.
CMI	Coastal Marine Institute Studies	Gulf of Alaska, Bering, Chukchi and Beaufort Seas	1992–present	• http://www.alaska.boemre.gov/ess • http://www.sfos.uaf.edu/cmi/
COMIDA	Chukchi Sea Offshore Monitoring in Drilling Area	Chukchi Sea	2009–present	http://www.comidacab.org/• http://www.alaska.boemre.gov/ess DSRII Special Issue 2014 (overview by Dunton et al. 2014)
CSESP	Chukchi Sea Environmental Studies Program	Chukchi Sea	2008-present	• Continental Shelf Research, 2013 (overview by Day et al. 2013)
IPY	International Polar Year	Northern Bering, Chukchi Sea, Arctic	2007–2009 (plus previous 1882-1883,1932–1933,	• Krupnik, I., et al., Editors. 2011. Understanding Earth's Polar Challenges: International Polar Year 2007–2008; http://www.icsu.org/publications/reports-and-reviews/ipy-summary/IPY-JC-Summary-Full.pdf • Grebmeier and Maslowski (2014)
ISHTAR	Inner Shelf Transport and Recycling	Northeastern Bering and Chukchi Seas	1983–1989	• Continental Shelf Research 13(5–6), 1993
OCSEAP	OCSEAP Outer Continental Shelf Environmental Assessment Program	Beaufort, Chukchi, eastern Bering Sea, and Gulf of Alaska	1975–1989	• Hood, D.W., and J.A. Calder, eds. 1981. Eastern Bering Sea Shelf: Oceanography and Resources, vols 1 & 2. US Department of Commerce, NOAA Office of Marine Pollution Assessment, Seattle, WA.
PCSP	Polar Continental Shelf Project	Arctic	1958–present	• Roots, E.F. 1962. Canadian Polar Continental Shelf Project, 1959–62. Polar Record 11, 270–76
RUSALCA	Russian-American Long-Term Census of the Arctic	Bering and Chukchi Seas	2004–present	• Deep-Sea Research II 57(1–2), 2010
SBI	Western Arctic Shelf-Basin Interactions	Chukchi and Beaufort Seas	1999-2008	• Deep-Sea Research II 52 (24–26), 2005 • Deep-Sea Research II 56 (17), 2009
SHEBA	Surface Heat Budget of the Arctic Ocean Project	Beaufort Sea	1995–2002	• Journal of Geophysical Research 107(C10), 2002.

The PacMARS effort has facilitated the accumulation and synthesis of a large number of data sets from the above programs as well as other data sets into products presented as highlights in the text to follow. A full listing of new data sets and metafiles uploaded to the PacMARS EOL data site are available in Appendix G4, with a cross-link file by document IDs with doi number provided in Appendix G5.

C1. Physical Oceanography

As is evident in Fig. B1.1 (in B. Methods section), there are many more data on the Alaskan side of the U.S.-Russia Convention Line than on the Russian side. Not surprisingly, many oceanographic casts have also been recently acquired in the offshore lease area north and west of Barrow where the potential for commercial oil and gas exploration has been highest. Separating these data by decade of acquisition shows that the fewest casts were acquired during the 1970s and 1990s (Fig. C1.1). However, the greatest numbers of casts in Russian waters were acquired during these two decades.

The inner coastal zone is probably the least studied region in the Chukchi and Beaufort seas, yet may be the most vulnerable to environmental change and impacts of industrial development. For example, Fig. C1.2-left panel portrays the influence of strong easterly winds that have created a suspended sediment plume along the Beaufort coast that flows around Pt. Barrow toward the southwest. By way of comparison, Fig. C1.2 (right panel) shows a MODIS true-color image of the Barrow region during very calm winds (0.3 m/s) a week later than observed in Fig. C1.2. The absence of the sediment plume suggests (confirmed by current meter moorings, but data not shown) that the circulation has changed and fish, zooplankton, organic material, and other particulate matter are retained on the Beaufort shelf. The degree to which the sediment plume is a reasonable tracer of near shore circulation, thus influencing the advection of fish, zooplankton, organic material, and other particulate matter from the shallow shelf to the deeper waters of Barrow Canyon is self-evident. During a nine-year study by Co-PIs Ashjian, Campbell, and Okkonen in the Barrow nearshore area, this phenomenon was observed multiple times.

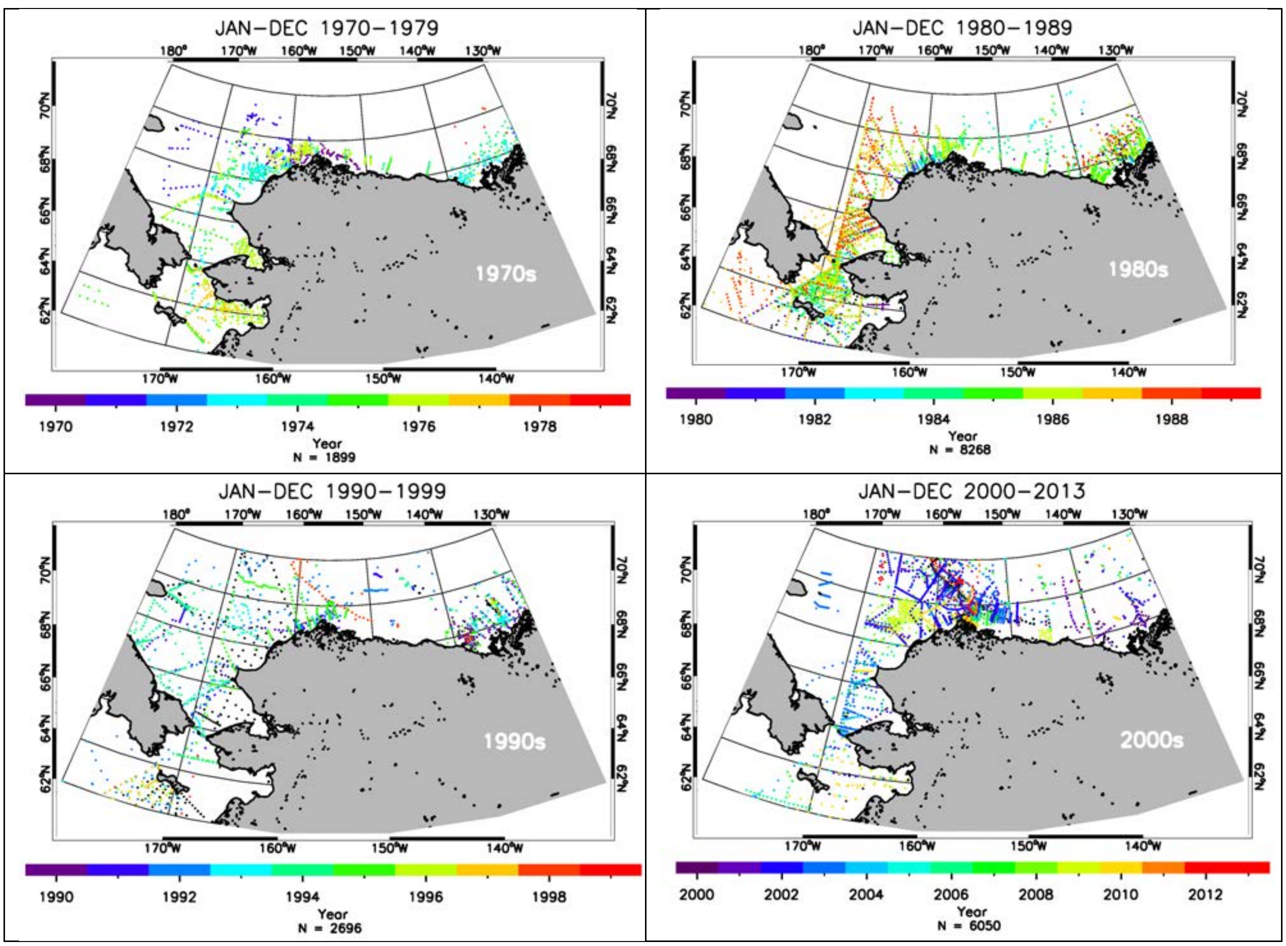


Figure C1.1 Maps showing the distribution of CTD casts grouped according to the decade of acquisition.

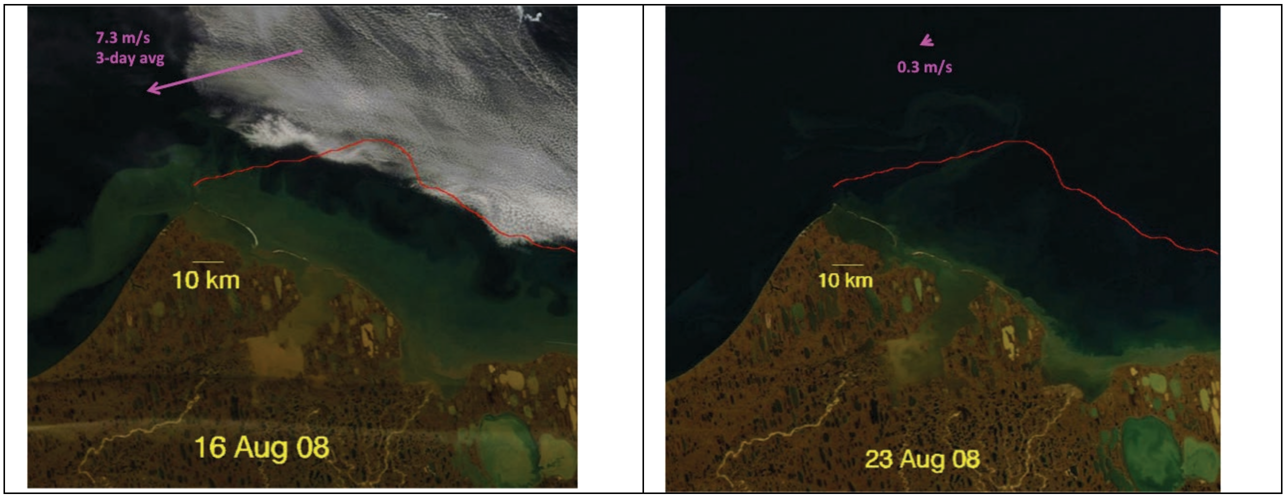


Figure C1.2 Left Panel. MODIS true-color image of the Barrow region following a period of strong (7.3 m/s), upwelling-favorable winds from the east. The red line depicts the 40-m isobath, nominally the shelf break in this area. Right panel. MODIS true-color image of the Barrow region during very calm winds (0.3 m/s) a week later than observed in the left panel of this figure.

Fig. C1.3 shows a time series of monthly-averaged National Centers for Environmental Prediction (NCEP) zonal wind velocities for the open water season, August-October 1970-2012 around Barrow. Winds from the west have positive speeds; winds from the east (upwelling-favorable) have negative speeds. The horizontal line at -6 m/s represents a rough threshold such that winds from the east that are stronger (more negative) than 6 m/s will reverse the circulation along the shelf break towards the west/southwest resulting in conditions similar to that depicted in Fig. C1.2. The wind time series plot appears to indicate that, for the 43-years shown, the general trend is toward stronger upwelling winds near Barrow during the open water months (particularly in September and October) and, by inference, toward an inner shelf ecosystem as shown in Fig. C1.2.

Regionally, the inner shelf coastal zone in both the Beaufort and Chukchi seas has not been evaluated in a systems mode. Changes in wind forcing dramatically alter the inner shelf domain and there is evidence that the Beaufort coast is increasingly influenced by the occurrence of strong, upwelling-favorable winds that might move the inner shelf ecosystem to a different state than has existed in recent decades.

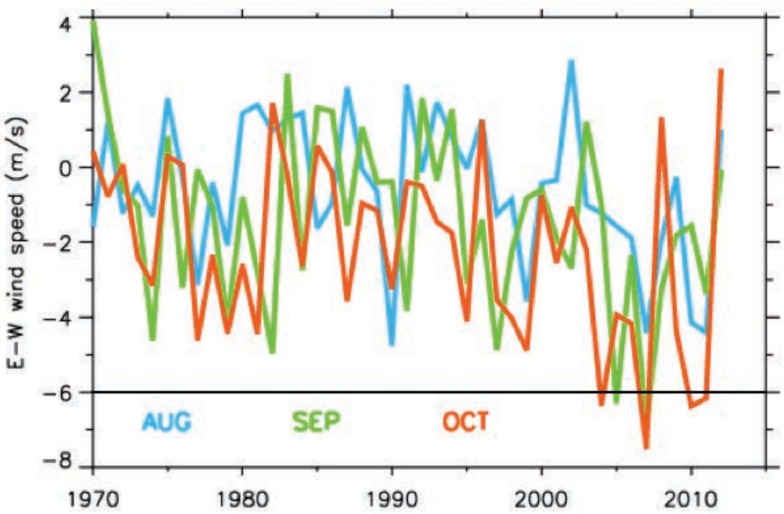


Figure C1.3 Time series of monthly-averaged NCEP zonal wind velocities for the open water season, August-October 1970-2012.

C2. Phytoplankton and Zooplankton in relation to CTD data

C2.1 Archived data sets

For both the chlorophyll and zooplankton data sets, a compilation file has been prepared that describes the key features of each data set (e.g., collection methods) and identifies the project and scientists who collected and/or compiled the data (Table C2.1). This effort could not have been accomplished without the collaboration of a number of investigators who willingly shared their data and the PIs are grateful to those colleagues for their assistance.

The gridded values of temperature from the CTD and integrated chlorophyll are archived as ASCII files with three columns containing longitude, latitude, and the variable of interest.

The integrated chlorophyll and zooplankton biomass data sets are archived, in addition to the raw data sets that were used to generate the zooplankton biomass data set. For each of the four copepod species that were focused upon, three files are included. The first (speciesname_All.xlsx) is a compilation of all of the data for each species and is presented as an Excel file since some of the data formats in the file would not translate well into ASCII format. Note that there are many more lines of data in these files than in the files presenting only the QA/QC data from the upper 100 m. The second file contains integrated biomass for the 0-100 m depth range for all of the life stages that were of an appropriate size to be captured in the net used and for which the appropriate sampling criteria were met (see below). The third file contains this same 0-100 m integrated biomass but is presented as an ASCII file. The compilation data were quality assured to integrate data over the upper 100 m. This was challenging because of the varying depth intervals over which the net tows were conducted (for example, 0-125 m). A set of criteria was developed to include data from locations where the sampling depths did not fall directly on the 0-100 m interval:

1) If the upper 30 m of the water column was not sampled (e.g., only 30-100 m was sampled), the tow was not included.

2) At deep stations, only tows that sampled >70% of the upper 100 m were also included.

3) Tows that sampled deeper than the upper 200 m were not included.

C2.2 Water temperature

Warmest sea surface summer temperatures within the PacMARS domain were observed in the southern Chukchi Sea and northern Bering Sea, particularly associated with the Alaska Coastal Current although there is evidence also of warm water extending northwards in the central Chukchi Sea (Fig. C2.1-Left panel). Sea surface temperature for these months has warmed considerably since 2005 relative to the period prior to 2005 (Fig. C2.1-right panel) across the entire study region. Temperatures increased most noticeably along the shelf break in the northern Chukchi Sea, just to the north of Point Hope, and in the Canada Basin. By contrast, bottom temperatures were similar between the two periods, with little warming observed (Fig. C2.2; point-by-point change not shown). Because of the increase in summer surface temperatures between the periods pre-2005 and post-2005, there is a larger temperature difference between surface and bottom waters in the post-2005 period relative to previous years (Fig. C2.3) at most locations in the Chukchi Sea. This was particularly notable in the northern Chukchi Sea. Comparison of the surface-bottom temperature differences at coincident locations between the two time periods showed that at many locations, the difference between the surface and bottom waters had increased by 2 degrees or more in the more recent period relative to pre-2005. The exception was in the northern Bering Sea where this differences between bottom and surface waters did not consistently increase and, at some locations, the differences decreased. The Alaska Coastal Current was evident in the bottom water temperature distribution. The average water column temperature had distribution patterns similar to those of surface temperature, with warmest water in the Alaska Coastal Current, and showed some evidence of warming during 2005 and later but this was not as widespread or pronounced as seen for the surface temperature (Fig. C2.4-left panel).

Table C2.1 Phytoplankton and zooplankton files archived in the EOL PacMARS data site.

Data Set Name	**Format**	**Description**
Zooplankton Data Set Compilation.xlsx	MS Excel	Listing of all the data sets on zooplankton abundance examined in this project. Includes specifics on collection year and region, gear used (net type, mesh size), project, people collecting the data, and alternative source for the data
Phytoplankton Data Set Compilation.xlsx	MS Excel	Listing of all the data sets on chlorophyll concentration examined in this project. Includes specifics on collection year and region, project, people collecting the data, and alternative source for the data
Summer_2005_Plus_AvgT_gridded_xyz.txt	ASCII	Average water column temperature for 2005 and later in July-September gridded from the PacMARS CTD compilation to a grid of 0.5 deg. Latitude from 63.5 to 78 N and 2 deg. Longitude from -180 to -135. There are three columns in the file, longitude, latitude, and temperature (°C). Missing values are denoted as NaN.
Summer_Pre2005_AvgT_gridded_xyz.txt	ASCII	As for above for years before 2005
Summer_2005_Plus_BottT_gridded_xyz.txt	ASCII	As for above for bottom temperature and 2005 and later
Summer_Pre2005_BottT_gridded_xyz.txt	ASCII	As for above for bottom temperature and years before 2005
Summer_2005_Plus_SurfT_gridded_xyz.txt	ASCII	As for above for surface temperature and 2005 and later
Summer_Pre2005_SurfT_gridded_xyz.txt	ASCII	As for above for surface temperature and years before 2005
Summer_2005_Plus_IntChl_gridded_xyz.txt	ASCII	As for above for Integrated Chlorophyll (mg m^{-2}) and 2005 and later
Summer_Pre2005_IntChl_gridded_xyz.txt	ASCII	As for above for Integrated Chlorophyll (mg m^{-2}) for years before 2005
Cglacialis_marshallae_All.xlsx	MS Excel	All of the compiled data for *C. glacialis/marshallae*
Cglacialis_marshallae_Upper100m_Total.xlsx	MS Excel	Integrated biomass (0-100 m) for samples of *C. glacialis/marshallae* that met the QA/QC criteria
Cglacialis_marshallae_Upper100m_Total.txt	ASCII	Integrated biomass (0-100 m) for samples of *C. glacialis/marshallae* that met the QA/QC criteria
Mpacifica_longa_All.xlsx	MS Excel	All of the compiled data for *M. pacifica/longa*
Mpacifica_longa_Upper100m_Total.xls	MS Excel	Integrated biomass (0-100 m) for samples of *M. pacifica/longa* that met the QA/QC criteria
Mpacifica_longa_Upper100m_Total.txt	ASCII	Integrated biomass (0-100 m) for samples of *M. pacifica/longa* that met the QA/QC criteria
Osimilis_all.xlsx	MS Excel	All of the compiled data for *O. similis*

Table C2.1 Phytoplankton and zooplankton files archived in the EOL PacMARS data site (cont).

Data Set Name	Format	Description
Osimilis_upper100m_Total.xlsx	MS Excel	Integrated biomass (0-100 m) for samples of *O similis* that met the QA/QC criteria
Osimilis_upper100m_Total.txt	ASCII	Integrated biomass (0-100 m) for samples of *O. similis* that met the QA/QC criteria
Pseudocalanus_All.xlsx	MS Excel	All of the compiled data for *Pseudocalanus spp.*
Pseudocalanus_Upper100m_Total.xlsx	MS Excel	Integrated biomass (0-100 m) for samples of *Pseudocalanus spp.* that met the QA/QC criteria
Pseudocalanus_Upper100m_Total.txt	ASCII	Integrated biomass (0-100 m) for samples of *Pseudocalanus spp.* that met the QA/QC criteria
CopepodStageWeights.xlsx	MS Excel	Carbon weights (µg C/individual) for each life stage of each species
CopepodWidths_and_NetMeshSizes.xlsx	MS Excel	Body widths used for each species/life stage
Description_of_Files.doc	MS Word	File descriptions

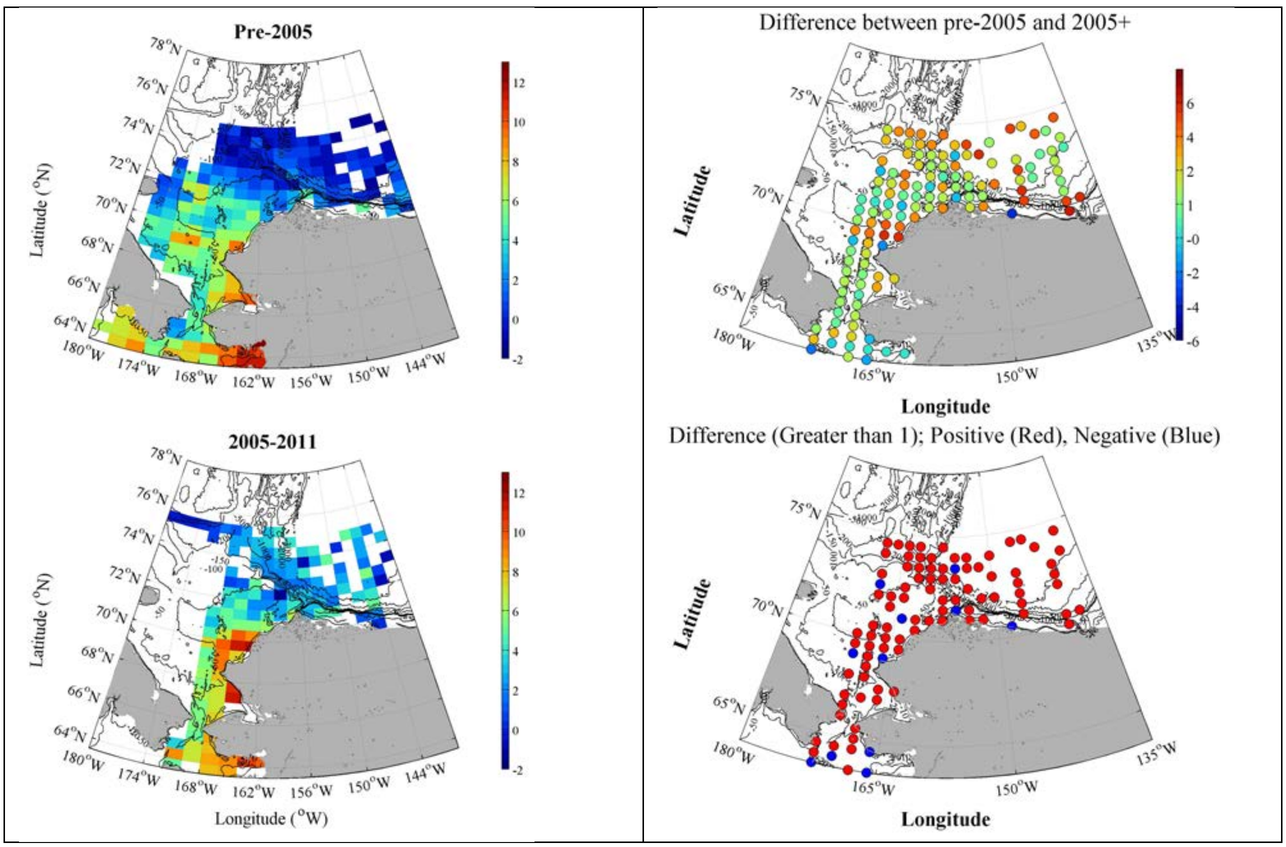


Figure C2.1 Left panel. Surface temperature during the summer (July-September) pre-2005 (left top) and 2005-2011 (left bottom). File=Summer_SfcT_TwoPeriods.jpg. **Right panel.** Difference in surface temperature between years pre-2005 and from 2005-2011 (right top), and locations where this difference exceeded +2 or -2 °C (right bottom). Differences were calculated from gridded values of surface temperature; grid points were calculated for every 0.5 °Latitude and every 2°Longitude. Difference only calculated for grid locations where data were available during both time periods.

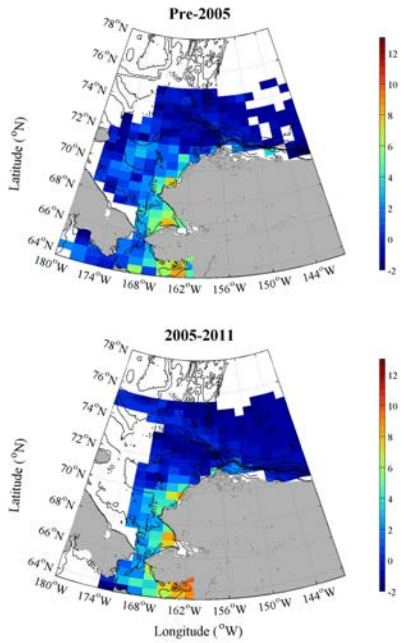


Figure C2.2 Bottom temperature during the summer (July-September) pre- 2005 (left top) and 2005-2011 (left bottom). File=Summer_BotT_TwoPeriods.jpg.

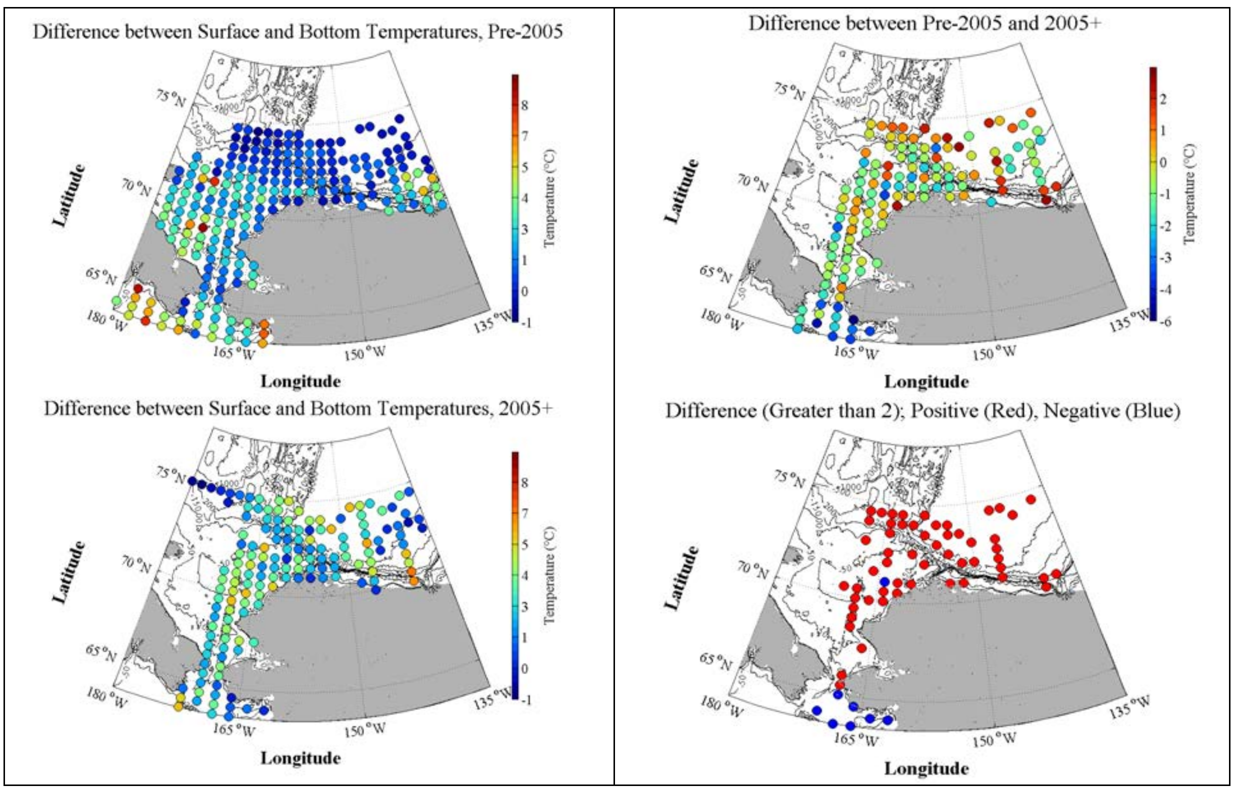


Figure C2.3 Left column Differences between surface and bottom temperatures for the period prior to 2005 and the period from 2005 and later, calculated from surface and bottom temperatures for each temporal period at locations where gridded data points were available. **Right column**. Differences between the two temporal periods in surface-bottom temperature difference and locations where that difference between periods was 2°C or more, in either positive or negative direction (right panel). For example, a positive value at a location indicates that the difference between the surface and bottom temperatures in the period post-2005 was greater than 2°C relative to that difference in the period prior to 2005.

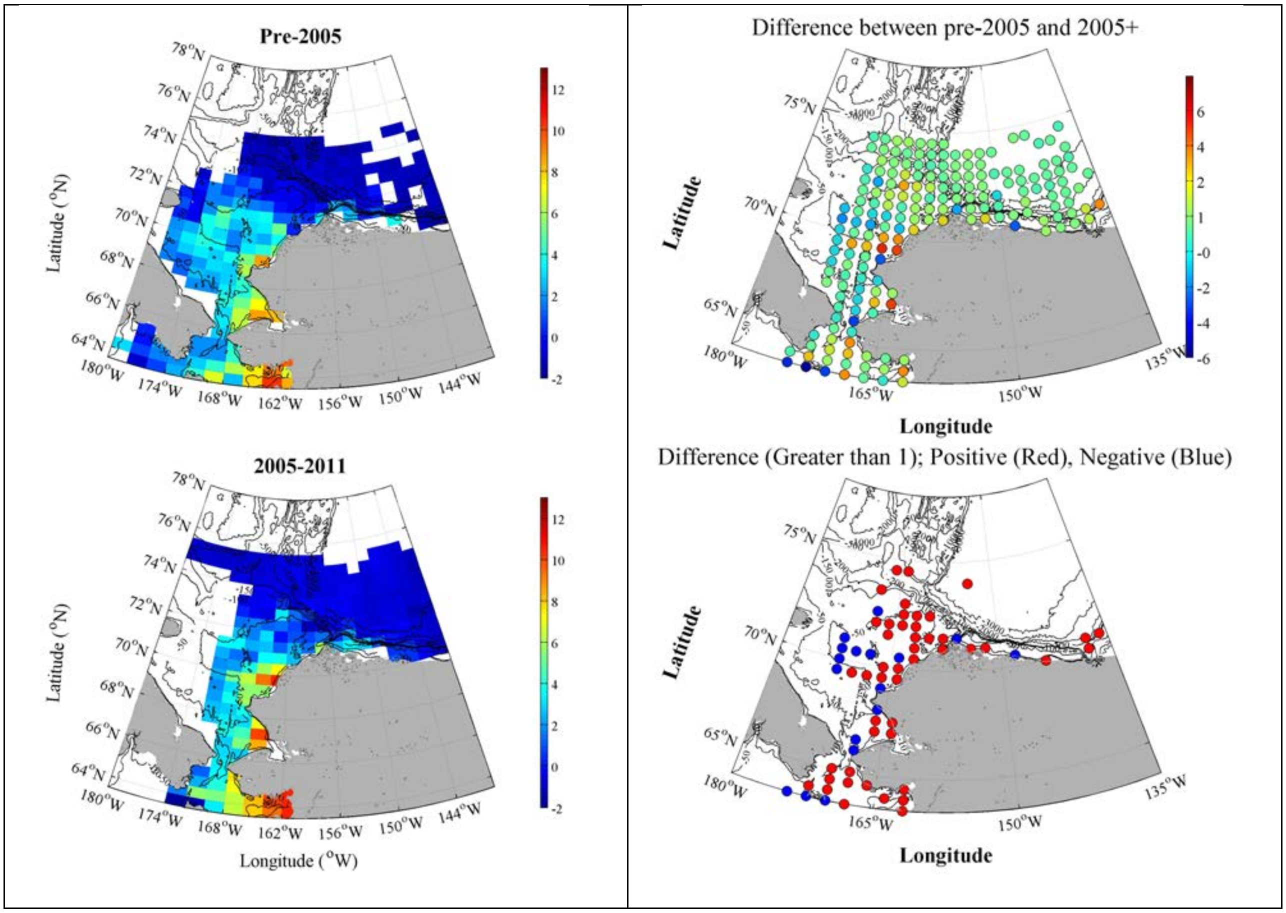


Figure C2.4 Left panel. Average water column temperature during the summer (July-September) pre-2005 (right top) and 2005-2011 (right bottom). Average water column temperature calculated from water column heat content. File=Summer_AvgT_TwoPeriods.jpg. **Right panel.** Difference in average water column temperature between the years pre-2005 and from 2005-2011 (top) and locations where this difference exceeded +2 or -2 °C (bottom). Differences were calculated from gridded values of surface temperature; grid points were calculated for every 0.5 °Latitude and every 2°Longitude. Difference only calculated for grid locations where data were available during both time periods. File=Summer_AvgT_change.jpg

C2.3 Chlorophyll

The chlorophyll data were primarily collected during the months of July-September (Fig. C2.6). Data collected during April-June and October-December unfortunately did not show spatial coincidence between the pre-2005 and the 2005 and later time period. Therefore the following analyses consider only data collected during the “summer” months (July-September).

Highest chlorophyll concentrations for both pre-2005 and 2005 and later were present along the Chukchi Shelf break, in the southern Chukchi Sea and particularly in the Anadyr Water, and, for pre-2005, in Herald Canyon to the east of Wrangel Island (Fig. C2.7-left panel). Chlorophyll concentrations were lower along the shelf break and in the southern Chukchi pre-2005 than during the 2005 and later period while values near Wrangel Island decreased in the later period (Fig. C2.7-right panel).

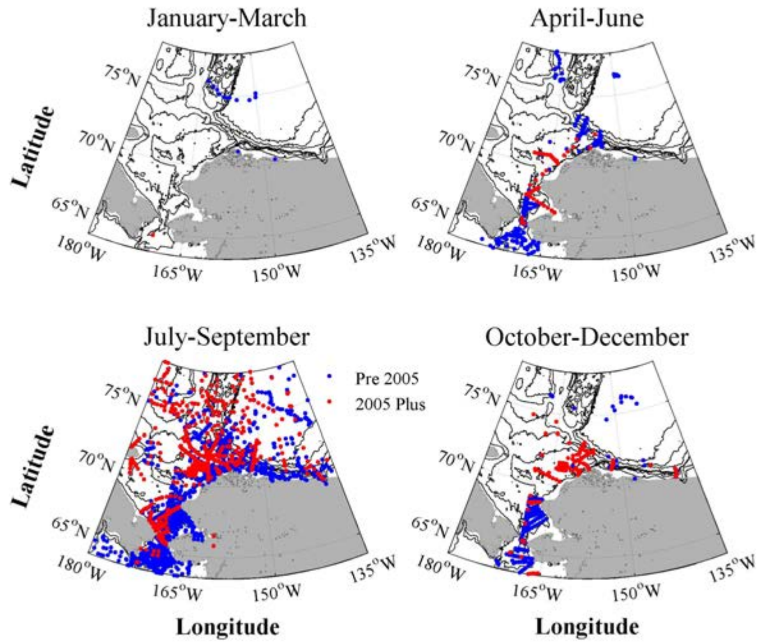


Figure C2.6 Locations of chlorophyll data used in the compilation. Locations are separated out by months of the year in which the casts were conducted and by year (pre-2005 and 2005 Plus). Altogether, data from 5089 casts locations are included. File=Chlorophyll_Positions.jpg

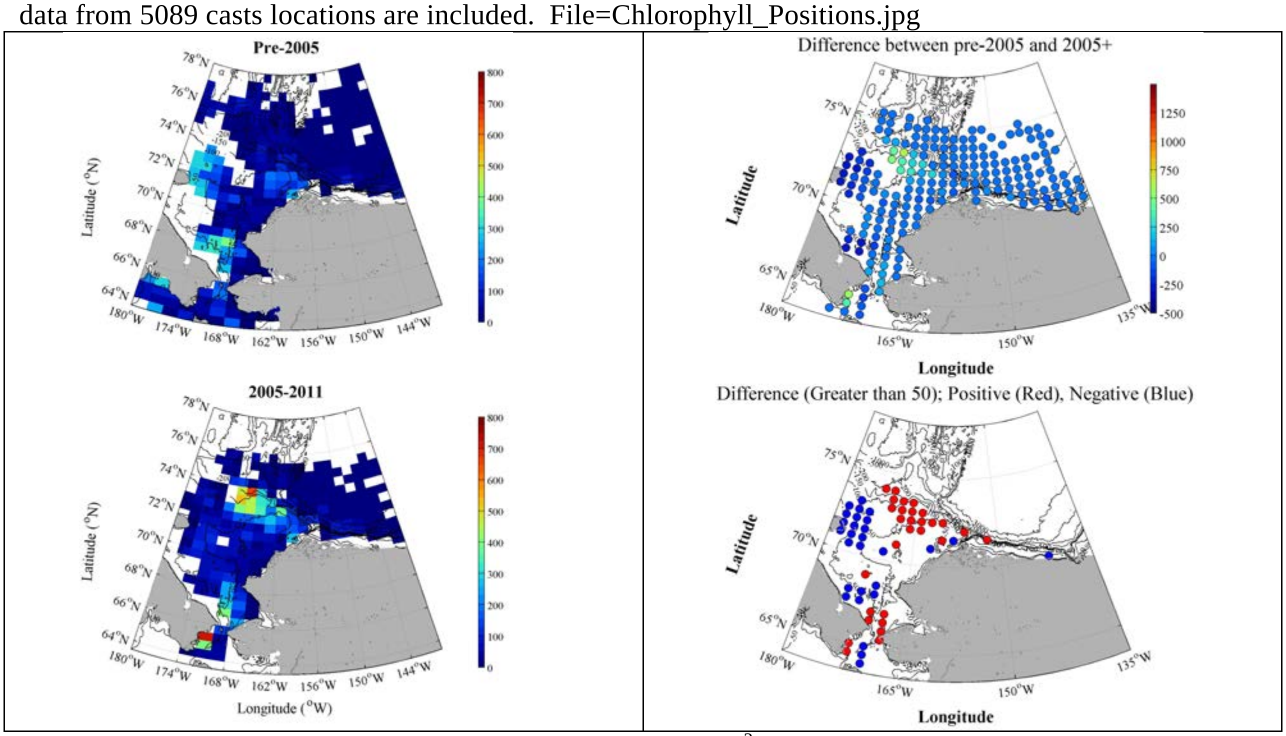


Figure C2.7 Left panel. Integrated chlorophyll (mg chl m^{-2}) for the upper 100 m or to the bottom in depths shallower than 100 m during summer (July-September) pre- 2005 (top) and 2005-2011 (bottom). File=IntChl_TwoPeriods_Summer_v6.jpg. **Right panel.** Difference in integrated water column chlorophyll (mg m^{-2}) between the years pre-2005 and from 2005-2011 (top) and locations where this difference exceeded +50 or -50 mg chl m^{-2} (bottom). Differences were calculated from gridded values of integrated chlorophyll; grid points were calculated for every 0.5 °Latitude and every 2°Longitude. Difference only calculated for grid locations where data were available during both time periods. File=Summer_IntChl_change.jpg.

C2.4 Zooplankton

C2.4.1 Seasonality of Sampling

As might be expected, there was a very strong seasonal bias in the availability of data, with most sampling occurring during the ice-free period in the summer and early fall (Fig. C2.8). This bias is even more pronounced in the recent post-2005 time-period than in earlier years. If one only considers the samples that could be used in the analysis for *Calanus glacialis/marshallae*, for example, 71%, 19%, 6%, and 4% were collected in the summer, fall, spring, and winter, respectively. Since the greatest volume of samples were available for the summer season, the summer season was selected as the time period in which to look for evidence of long-term changes in distribution patterns or biomass.

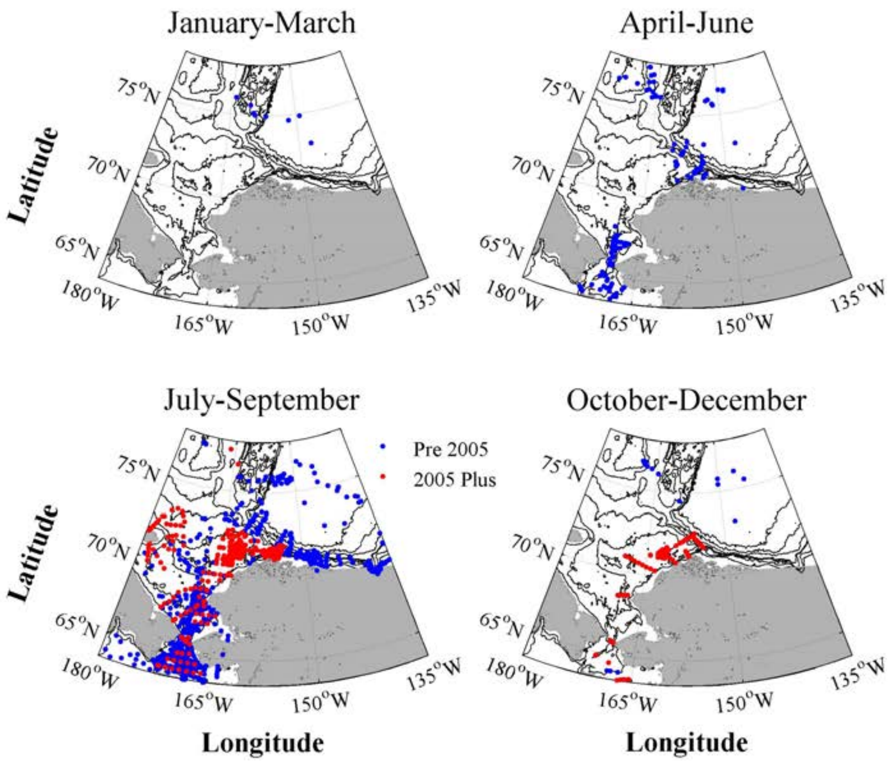


Figure C2.8 Locations of zooplankton tows examined in the analysis. Locations are separated out by months of the year in which the casts were conducted and by year (pre-2005 and post-2005). Altogether, 2000 stations were located within the geographic boundaries of 63.5-78 °N and -180 to -135 °W. File=AllZoopStationsbySeasonPeriod.jpg

C2.4.2 Time Periods

The data sets were separated out by time period in an attempt to determine if changes in the biomass distribution patterns have occurred over time (Figs. C2.9-C2.12. Four time periods were chosen, pre-1980, 1980-1989, 1990-2005, and 2005+. For the pre-1980 time period there were very few data sets available that could be used in the analysis because they did not meet the criteria put forth in the Zooplankton Methods section, and those that were available were limited to the deep Canada Basin. Likewise, there were few data sets that were available for the 1980-1989 time period, and all were restricted to the far eastern Beaufort Sea shelf. A higher concentration of samples occurred along the northern Chukchi and western Beaufort shelf break during the 1990-2005 time period, with some samples from the deep basin as well. In recent years, post-2005, a considerable number of samples have been collected in the Chukchi Sea and the northern Bering Sea. Of note, there is very little overlap in the sampling locations between periods, which makes comparisons between the time periods difficult at best.

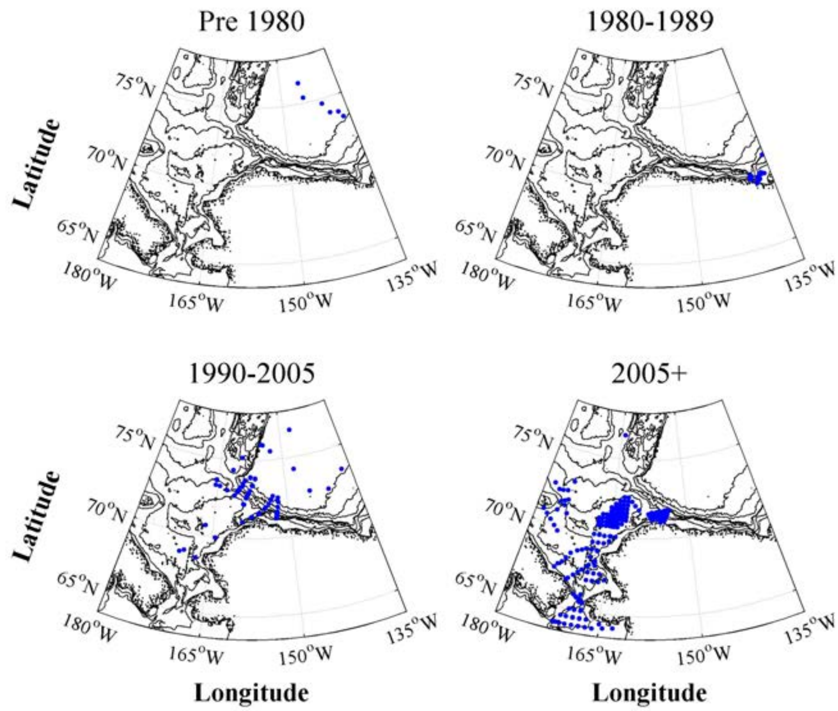


Figure C2.9 *Calanus glacialis/marshallae* (C1-adult). Locations of net samples (716) included in the compilation for each time-period during summer (July-September).
File= CglacBiomass_Summer_By_Year.jpg

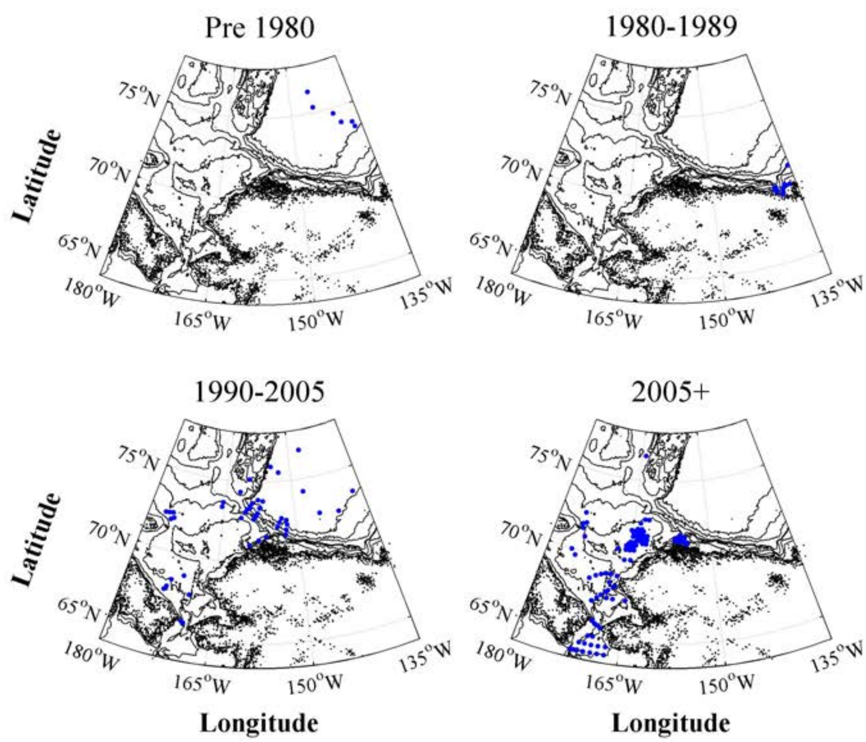


Figure C2.10 *Metridia* spp. (C3-adult). Locations of net samples (243) included in the compilation for each time-period during summer (July-September). File= Metridia_C3Plus_Summer_By_Year.jpg

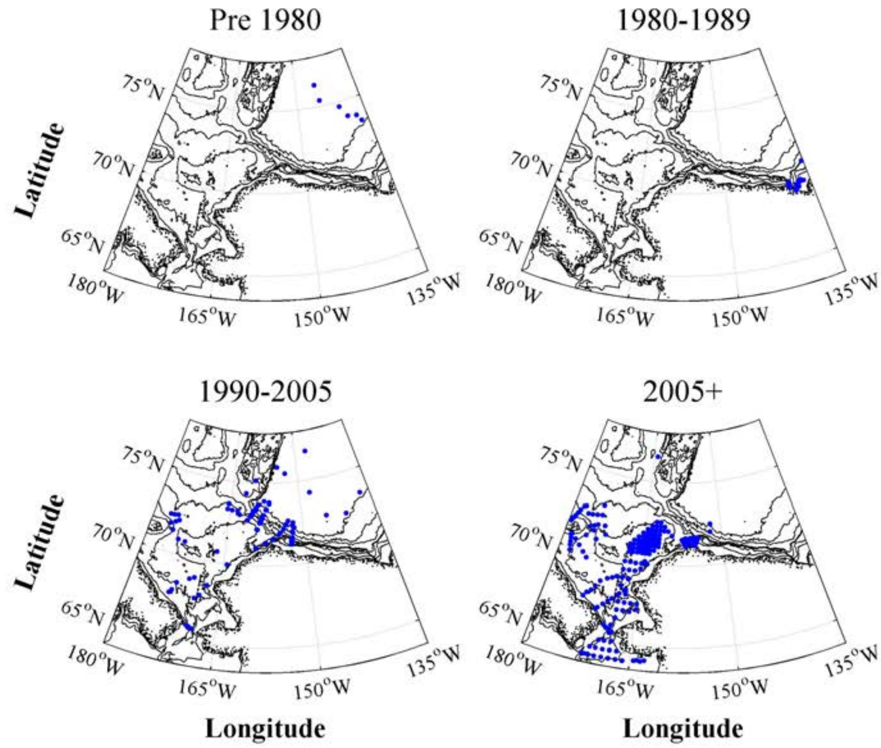


Figure C2.11 *Oithona similis* (adult only). Locations of net samples (836) included in the compilation for each time-period during summer (July-September). File= Oithona_Adults_Summer_By_Year.jpg

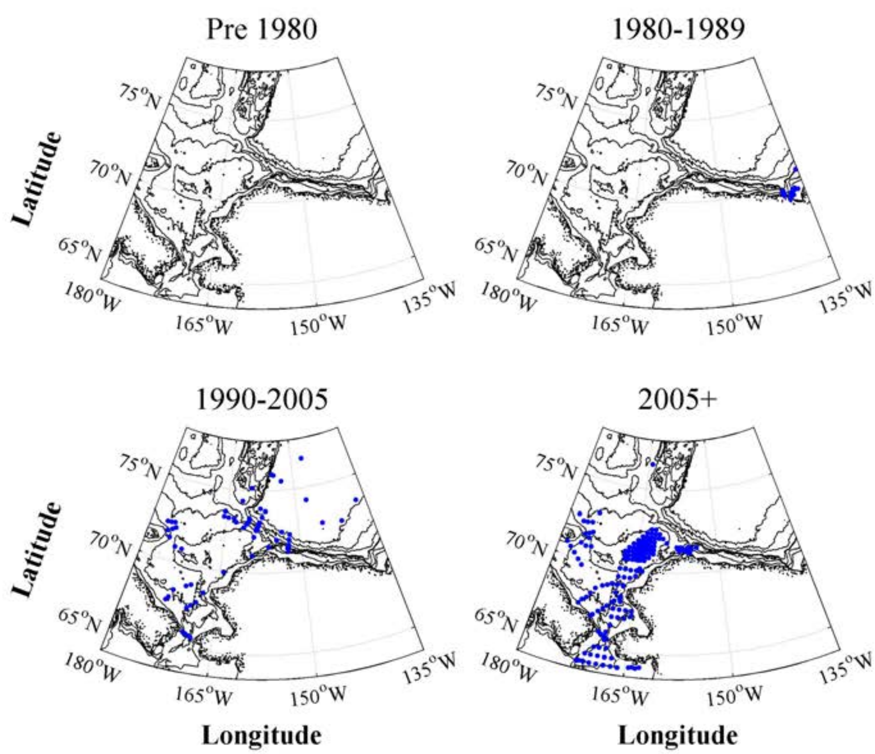


Figure C2.12 *Pseudocalanus* spp. (C3-adult). Locations of net samples (565) included in the compilation for each time-period during summer (July-September).

C2.5 Spatial patterns in copepod biomass

All four species show elevated biomass along the northern Chukchi and western Beaufort shelf break (Figs. C2.13a-d), although the biomass peak is not as distinct for *C. glacialis/marshallae* as for the other three species.. For *C. glacialis/marshallae* and *Pseudocalanus* spp. the peaks in biomass occur at the break in the region of steepest topography, while for *Metridia* spp. and *Oithona similis* the peaks occur in slightly deeper water just offshore in the basin. This is an expected pattern as *Calanus glacialis/marshallae* and *Pseudocalanus* spp. are normally found in close association with the shelf, while *Metridia* spp. and *Oithona similis* are often more abundant in deeper water. In addition, *Calanus* has an additional peak in biomass on the central Chukchi shelf. It is not clear if these distribution patterns are the result of in situ growth, advection, or some combination. These are not regions of high chlorophyll concentration (Fig. C2.7). However, there are regions of high chlorophyll directly downstream of these regions on the northern and southern Chukchi shelf. It may be that the distributional patterns in biomass are the result of accumulated advected biomass from downstream where growth conditions are more favorable. This obviously needs further study.

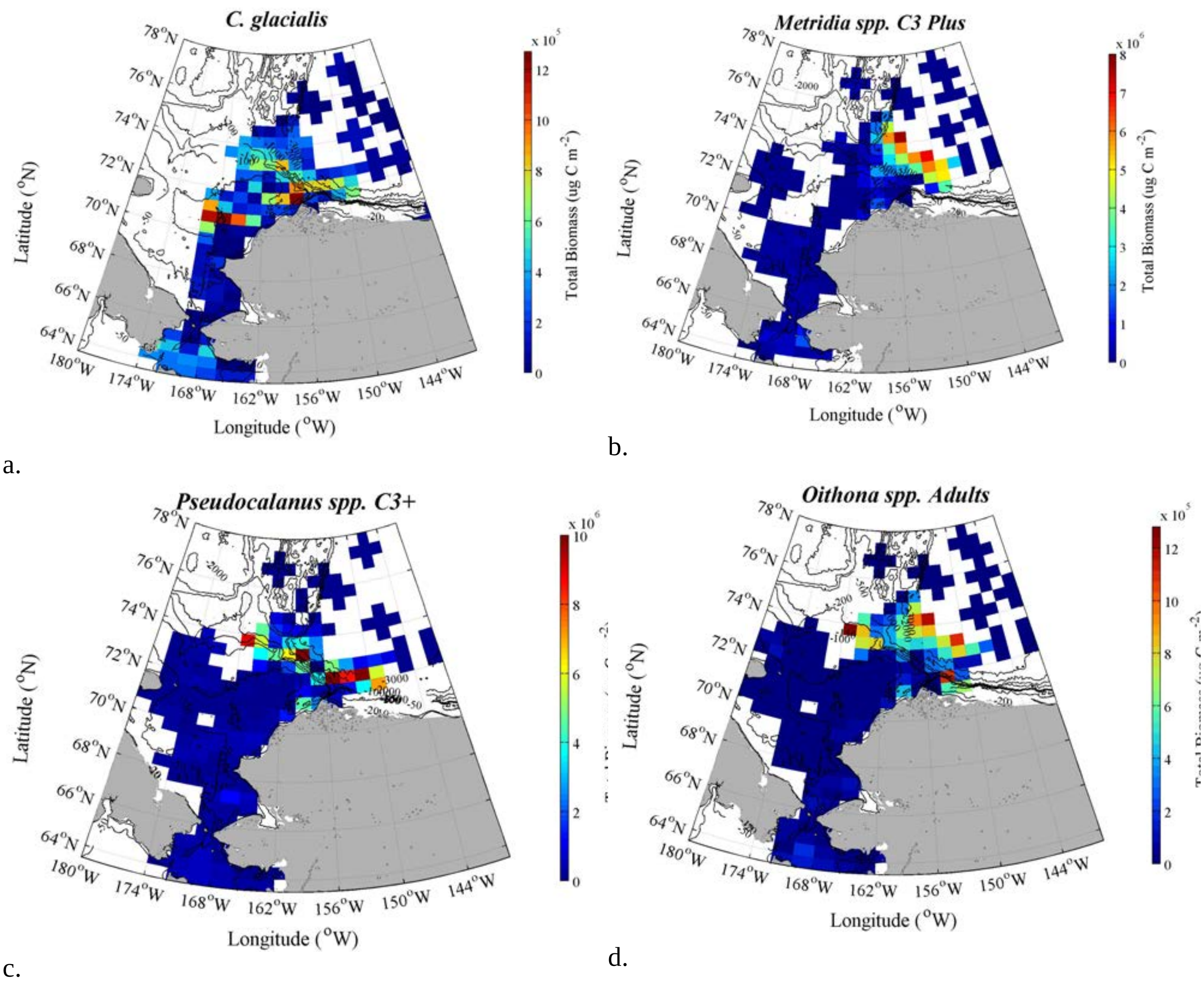


Figure C2.13 Integrated (surface to bottom or 100 m in deeper water) water column biomass (µg carbon m^{-2}) of a. *Calanus glacialis/marshallae* (C1-adult), b. *Metridia* spp. (C3-adult), c. *Pseudocalanus* spp. (C3-adult), and d. *Oithona similis* (adult only) during summer (July-September).

C2.6 Syntheses of phytoplankton (chlorophyll), zooplankton, and water temperature distributions

C2.5.1. Spatial Distributions of High Chlorophyll and Copepod Biomass

The spatial distributions of particularly high chlorophyll and copepod biomass were further explored by identifying those gridded values that exceeded two or three standard deviations from the mean for each of the available data sets (chlorophyll pre-2005 and 2005 and later and the four copepods) and mapping them spatially (Figs. C2.13 and C2.14). For chlorophyll, there was some overlap between the locations of high biomass between the pre-2005 and the 2005 and later data such as in the southern Chukchi just to the north of the Bering Strait and in Barrow Canyon. However, for both time periods unique groupings of stations in specific regions were observed. For the early period, highest biomass was seen in the region near Herald Canyon to the east of Wrangel Island, Hanna Shoal, and a larger region in the Anadyr Current. After 2005, however, these regions were less prominent and the region of the Chukchi Sea to the west of Hanna Shoal and to north of the Central Channel on the Chukchi Shelf had the highest biomass.

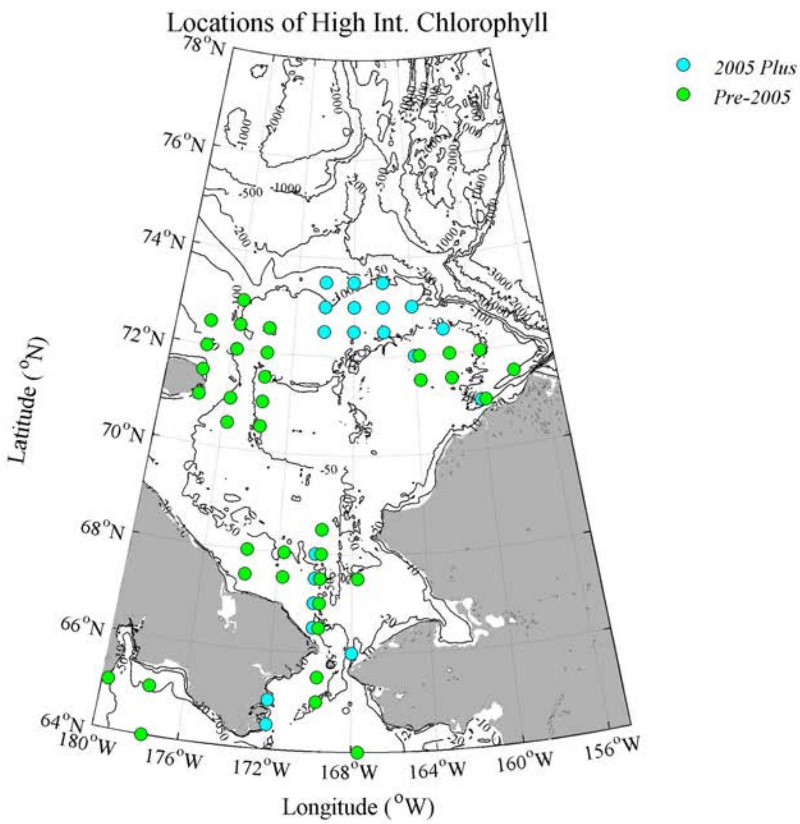


Figure C2.14 Locations where the integrated water column (0-100 m) biomass of chlorophyll (mg m^{-2}) exceeded 2 standard deviations of the mean integrated biomass based on gridded values, for the periods before 2005 and 2005 and later. Bottom topography from IBCAO 3.0. File=IntChl_LocationsofHighValue.jpg

The maximum biomass of the four copepod species was for the most part spatially discrete, although two species had similar distributions (Fig. C2.15). Both *Metridia* spp. and *Oithona similis* had maximum biomass off of the shelf, in the Canada Basin, generally in water greater than 100 m (although note that *O. similis* had high biomass also in the Herald Valley). Maximum biomass of *Pseudocalanus* spp. was observed along the shelf break. Maximum biomass of *Calanus* spp. was observed along the shelf break but also around the periphery of Hanna Shoal to the south. These latter copepods likely were advected from the south from the Bering Sea while the *Calanus* spp. was observed in the western Chukchi in

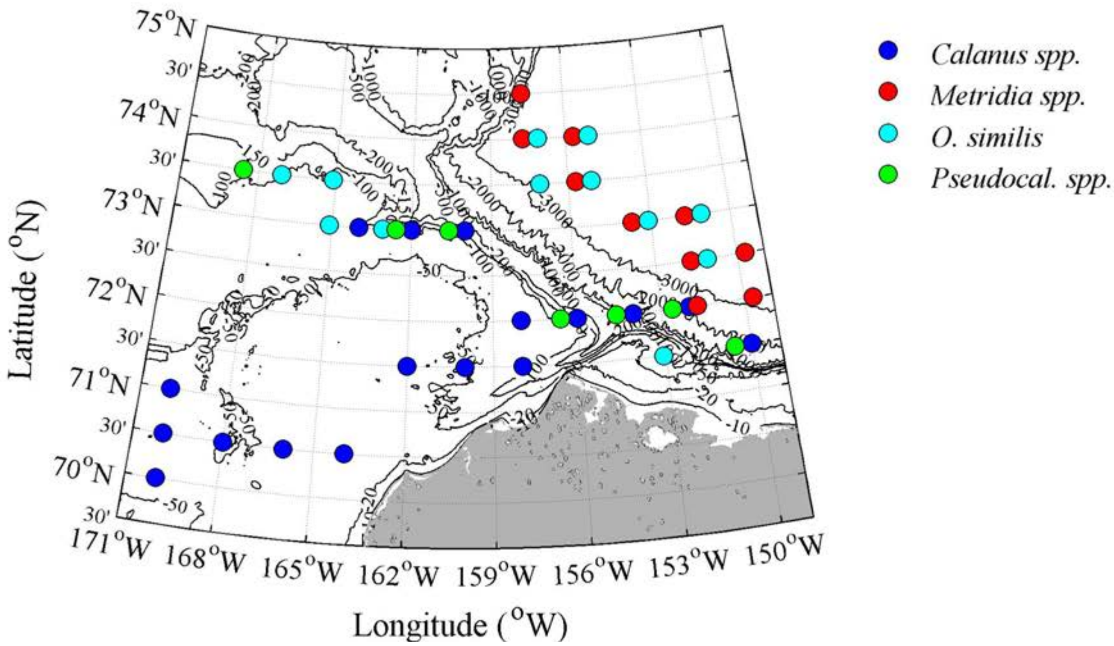


Figure C2.15 Locations where the integrated water column (0-100 m) biomass (µg C m^{-2}) exceeded 2 or 3 standard deviations of the mean integrated biomas for the four target copepod species, based on gridded values. Two standard deviations were used for *Metridia, O. similis,* and *Pseudocalanus* spp. while three standard deviations were used for *Calanus* spp. in order to identify both the central and the northern Chukchi Shelf regions of localized biomass. No biomass maxima were observed to the south of 69.5°N. Bottom topography from IBCAO 3.0. File=Copepods_Locationsofhighabd.jpg

association with the location of northward flowing Anadyr Current. These copepods likely were advected from the south from the Bering Sea.

C2.5.2. Correlations between temperature, chlorophyll, and copepod biomass

The interpolated values at each grid point were compared for all of the variables to identify correlations that would be associated with similar spatial distributions (Table C2.3). Not surprisingly, there were good correlations (r=~0.74 or greater) between most temperature variables (surface temperature, bottom temperature, average water column temperature) even between the pre-2005 and 2005 and later periods, suggesting that temperature shows strong spatial patterns. The one exception was that the temperature difference between surface and bottom water for 2005 and later was only moderately or, for most comparisons, poorly correlated with other temperature metrics. There was little correlation between temperature and integrated water column chlorophyll or any copepod species biomass. Chlorophyll was likewise very poorly correlated with the biomass of any of the copepod species. This may not be surprising since this is a highly advective environment where zooplankton biomass at a given location largely represents growth conditions at upstream locations and thus the abundances of phytoplankton and zooplankton may be decoupled. *Oithona similis* and *Metridia* spp. were well correlated (r=0.715) while *Pseudocalanus* spp and *Oithona similis* were moderately correlated (r=0.5212). *Calanus glacialis/marshallae* was not correlated with the other three species.

Table C2.3 Correlation coefficients between gridded values for the physical and biological characteristics considered in this analysis. Correlations were calculated only for gridpoints where values had been interpolated for both of the variables being compared. Values greater than 0.7 are shaded with light gray.

Variables: Average Temperature (AvgT) before and 2005 and later; Surface Temperature (SurfT) before and 2005 and later; Bottom temperature (BotT) before and 2005 and later; Surface Temperature – Bottom Temperature (TDiff) before 2005 and 2005 and later; Chlorophyll (IntChl) before and 2005 and later; *Calanus glacialis* all copepodid and adult stages (Cglac), *Metridia* spp. Copepodid C3 and older (*Metridia* C3Plus), *Oithona similis* adults, *Pseudocalanus* spp. copepodid C3 and older (PcalC3Plus).

	Pre2005_ AvgT	2005Plus AvgT	Pre2005_ BotT	2005Plus BotT	Pre2005 SurfT	2005Plus SurfT	Pre2005 TDiff	2005Plus TDiff	Pre2005 IntChl	2005Plus IntChl	Cglac All	Metridia C3Plus	Oithona Adults	Pcal C3Plus
Pre2005_AvgT	1	0.89	0.94	0.88	0.88	0.76	0.40	-0.07	0.02	0.02	0.10	-0.31	-0.36	-0.34
2005Plus AvgT		1	0.86	0.95	0.86	0.86	0.49	0.06	0.14	0.08	0.07	-0.26	-0.29	-0.29
Pre2005_BotT			1	0.87	0.79	0.74	0.19	-0.10	-0.04	0.05	0.00	0.23	-0.27	-0.24
2005Plus BotT				1	0.84	0.80	0.43	-0.12	0.11	0.05	0.05	-0.22	-0.24	-0.20
Pre2005 SurfT					1	0.80	0.75	0.04	0.10	-0.08	0.21	-0.34	-0.42	-0.36
2005Plus SurfT						1	0.53	0.51	0.03	0.00	0.02	-0.23	-0.29	-0.29
Pre2005 TDiff							1	0.59	0.20	-0.17	0.34	-0.28	-0.38	-0.30
2005Plus TDiff								1	-0.04	-0.08	0.00	-0.08	-0.12	-0.17
Pre2005 IntChl									1	0.23	0.22	-0.18	-0.16	-0.08
2005Plus IntChl										1	0.01	-0.17	0.13	0.18
Cglac All											1	-0.07	-0.08	-0.01
Metridia C3Plus												1	0.72	0.28
Oithona Adults													1	0.52
Pcal C3Plus														1

C3. Macroinfaunal Populations, Sediment Parameters and Coincident Integrated Chlorophyll and Bottom Water Nutrients

C3.1 Macroinfaunal populations

As discussed in the introduction, an understanding of the geography of benthic infaunal communities in the northern Bering, Chukchi, and Beaufort seas can be organized around localized continental shelf "hotspots" of benthic biomass that serve as points of high carbon deposition that are directly tied to hydrographic processes that bring high nutrients onto the shelf and support high algal production. In some cases, these locations are often where a reduction of current speeds facilitates higher export production of particulate carbon to the benthos (Grebmeier et al. 2006a), which is in turn utilized by benthic filter and deposit feeders (Fig. C3.1; further citations in Grebmeier 2012, Nelson et al. 2014).

Through our decadal synthesis effort we are observing persistent patterns of benthic biomass and dominant infauna, although more focused, smaller region scales analyses are indicating declines and spatial contraction and northward extension of certain benthic hotspots over time. As part of the PacMARS synthesis effort we have uploaded 4 decades of macroinfauna abundance and biomass data to the PacMARS EOL data archive. The biomass data show the persistent pattern of enriched biomass of bivalves and polychaetes on the western side of the system under Anadyr water from the northern Bering to Chukchi Sea. In the offshore NE Chukchi Sea, bivalves, polychaetes and sipuculids dominate the benthic macrofauna, with amphipods becoming more prevalent closer to shore in the NE Chukchi Sea region off Alaska. In comparison, the region north of St. Lawrence Island in offshore areas is also dominated by amphipods that are a key prey source for gray whales. (Fig. C3.1). Fig. C3.2 is a plot of the same composite of benthic biomass, but presented in a variable colored dot version as present on the EOL PacMARS website.

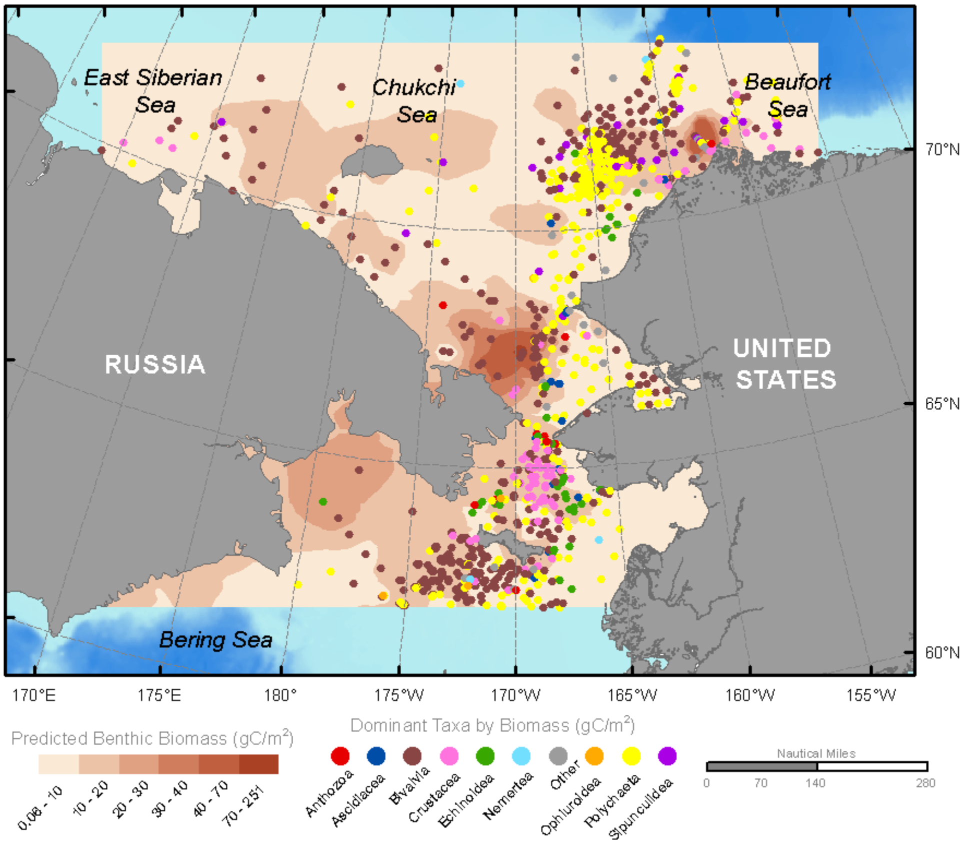


Figure C3.1 Distribution of macroinfaunal station biomass (gC/m2) and dominant infaunal over 4 decades (1970-2012) in the PacMARS area. Modified and updated from Bluhm and Grebmeier (2011).

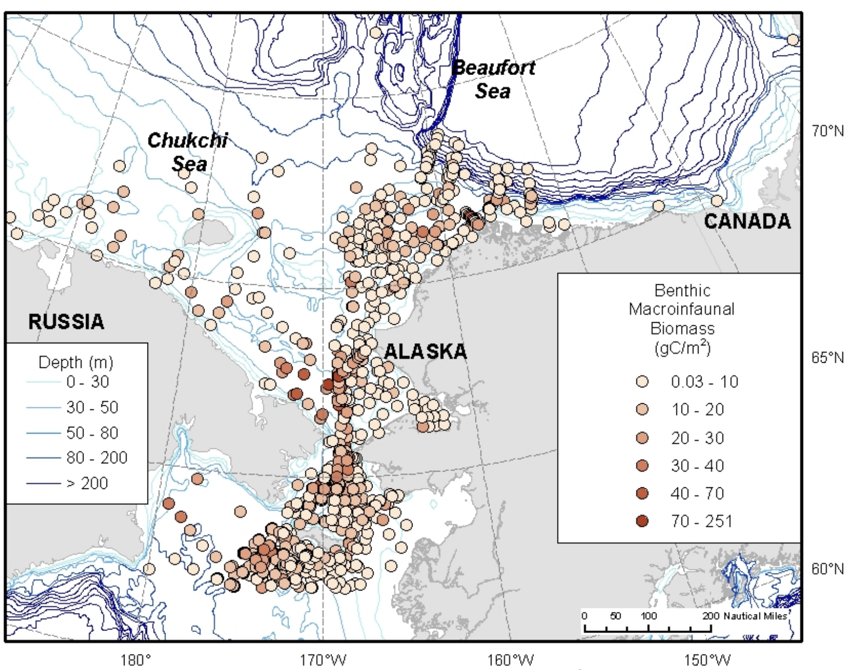


Figure C3.2 Distribution of benthic macroinfaunal biomass (gC/m^2) in the northern Bering and Chukchi Sea in a sample point version as it appears on EOL PacMARS website, 1970-2012.

Fig. C3.3 is a composite map of the benthic macroinfaunal data in gram wet weight (g wet wt) per m^2 for comparison, inclusive of data further east in the Beaufort Sea where infaunal composition values were not always available for carbon conversion estimates. The areas of highest benthic biomass in g wet wt/m^2 are similar to the gC benthic biomass, and coincide with the productive Anadyr water to the west in the SE Chukchi Sea that also has the higher standing tock of chlorophyll (see previous chlorophyll section).

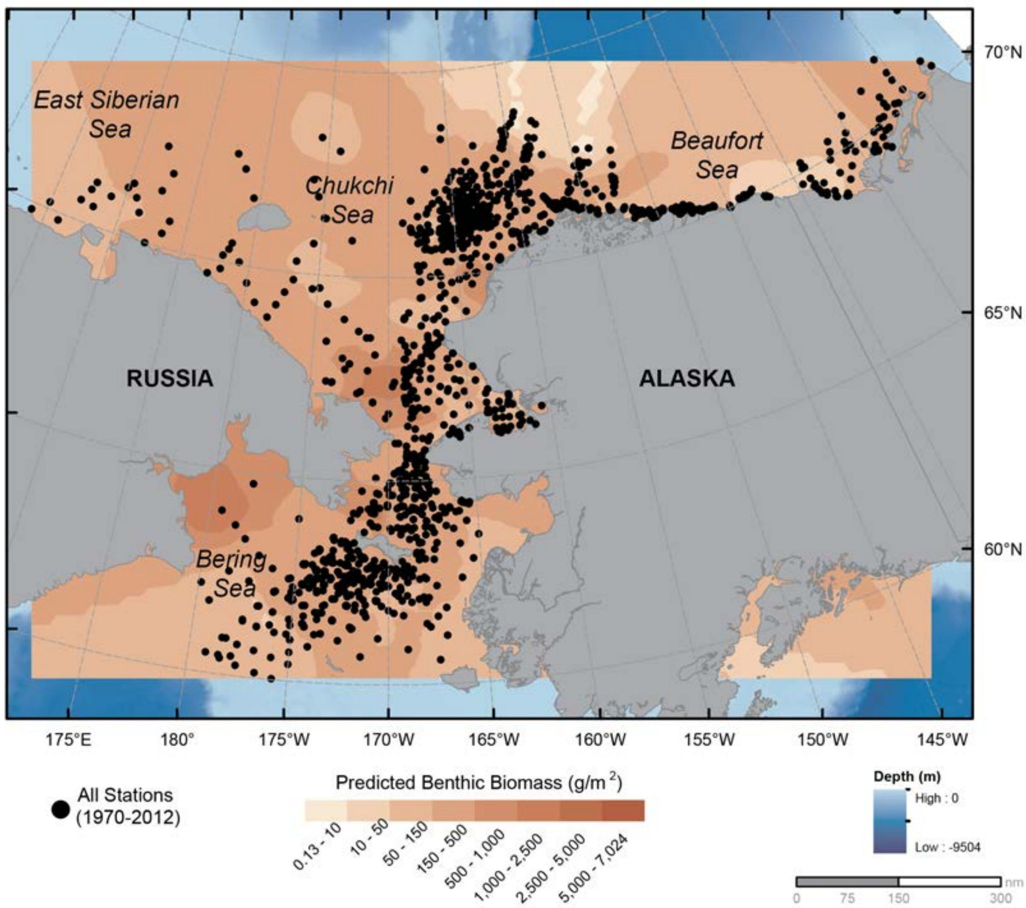


Figure C3.3 Distribution of benthic macroinfaunal biomass (g wet weight/m^2) in the northern Bering Chukchi, and Beaufort seas, interpolated version, 1970-2012.

As an example of benthic "hotspot" sites, Fig. C3.4 indicates the benthic biomass values for the 2000-2010 period with the continued location of the benthic hotspot sites relative to the overall range of values for the region. The regions SW of St. Lawrence Island, the NE Bering Sea, the SE Chukchi Sea and NE Chukchi Sea are areas of persistently high macrofaunal benthic biomass, many are which correlated to persisten areas of high water column productivity (see sections C2.3).

Figure C3.5 is a gridded map of benthic biomass through the year 2004 and from 2005-2012 following methods for gridding descript by PI Ashjian (Section B). For the PacMARS region north of St. Lawrence Island we observed a decline in benthic standing stock in the southern region of the Chirikov Basin, with most of the observed increase in benthic biomass in the northern region near Bering Strait. A similar pattern is observed for the benthic biomass patterns in the persistent hotspot in the southern Chukchi Sea, with southern sites declining and northern region offshore Pt. Hope increasing. In the NE Chukchi Sea we are beginning to see an increase in benthic biomass in the offshore areas, yet intermixed with areas of decline, indicative of the heterogenous nature of this site. Notably the post-2005 increase in

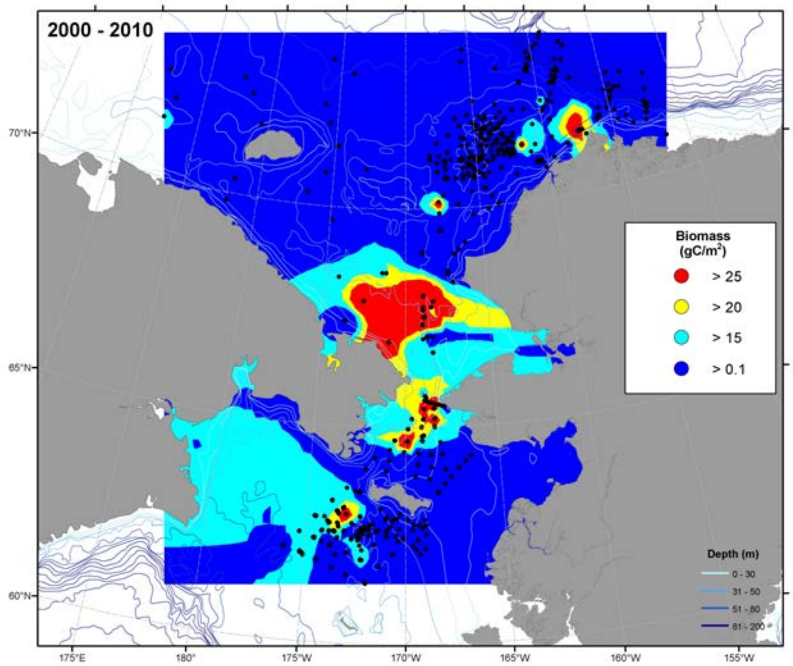


Figure C3.4 Distribution of station macroinfaunal biomass over the 2000-2010 period showing persistent hotspots of benthic macroinfaunl biomass.

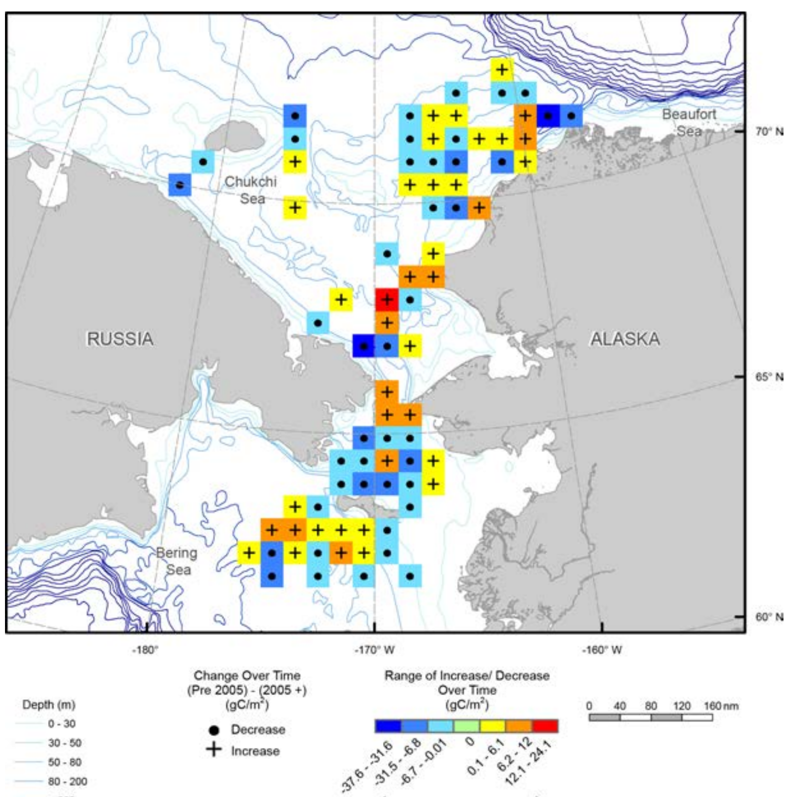


Figure C3.5 Distribution of gridded benthic station biomass data (gC/m2) for period pre-2005 and post-2005.

benthic biomass in both the SE and NE Chukchi Sea correspond to the post-2005 higher integrated chlorophyll levels observed during that period (see C2.7, right panel) and C2.14), likely indicative of a higher export of chlorophyll biomass to the benthos in the recent period with reduced sea ice persistence. There is a need for continued time series tracking of water column and macroinfaunal benthic stocks and processes as the ecosystem continues to change in the region.

Benthic taxon richness varies across the PacMARS area, with richer macroinfaunal diversity on portions of the shelf and upper slope (Fig. C3.6). Often areas of high infaunal biomass have low taxonomic diversity as a few species are able to dominate locally. It is unclear how biodiversity will change with climate warming and changing export production, and these issues remain an important question for future research. Changes in biodiversity and benthic community composition has a direct influence on carbon cycling in this benthic dominated system and the rich prey base is critical for upper trophic organisms such as gray whales, walrus, and bearded seals.

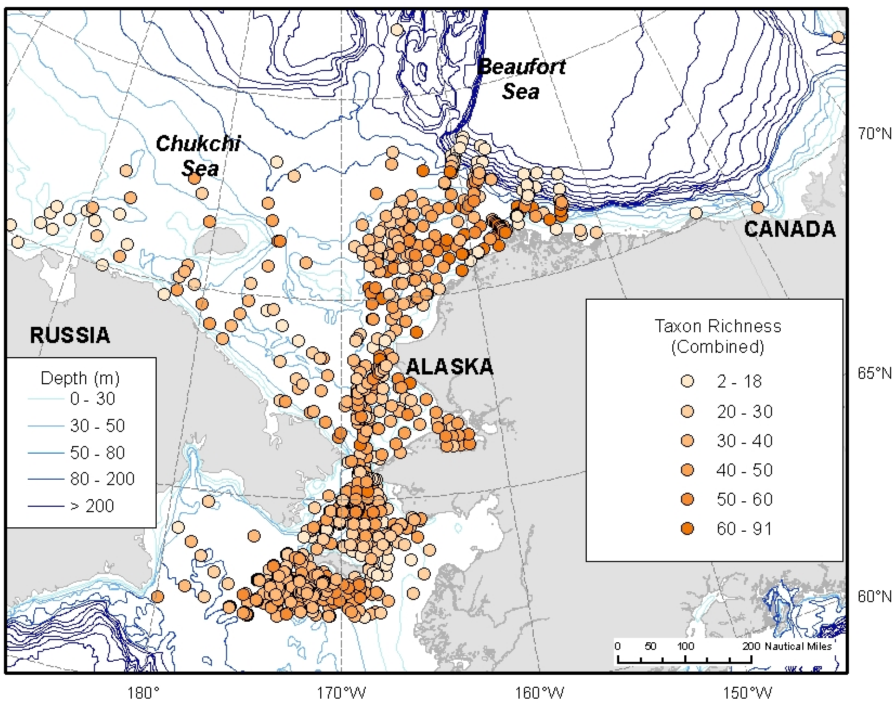


Figure C3.6 Distribution of taxon richness (taxon number, by family), 1974-2012 (point version).

C3.2 Sediment parameters

Benthic community composition is directly linked to sediment total organic carbon (TOC) content and grain size. Fig. C3.7 shows the spatial extent of surface sediment TOC that indicates deposition zones southwest of St. Lawrence Island, in the offshore regions of the Chukchi Sea and in the western Chukchi Sea and East Siberian Sea off the Russian coast, and along the Chukchi Sea slope regions. Notably the high silt and clay fractions of the surface sediments (Fig. C3.8) indicate the high deposition zones (and slower currents) in the PacMARS region in the SE Chukchi Sea. This region is coincident with the high seasonal chlorophyll standing stocks and primary production in the region (see Section C2 above), known for providing high export production to the benthos (Grebmeier 2012). Notably the region north of St. Lawrence Island has lower silt and clay (≥5 phi), with high sand content in this region of high advective flow and benthic amphipods. Areas in the NE Chukchi Sea have variability patterns. Ongoing analyses are evaluating these and other driving factors for benthic macroinfaunal populations and changes overtime in this region.

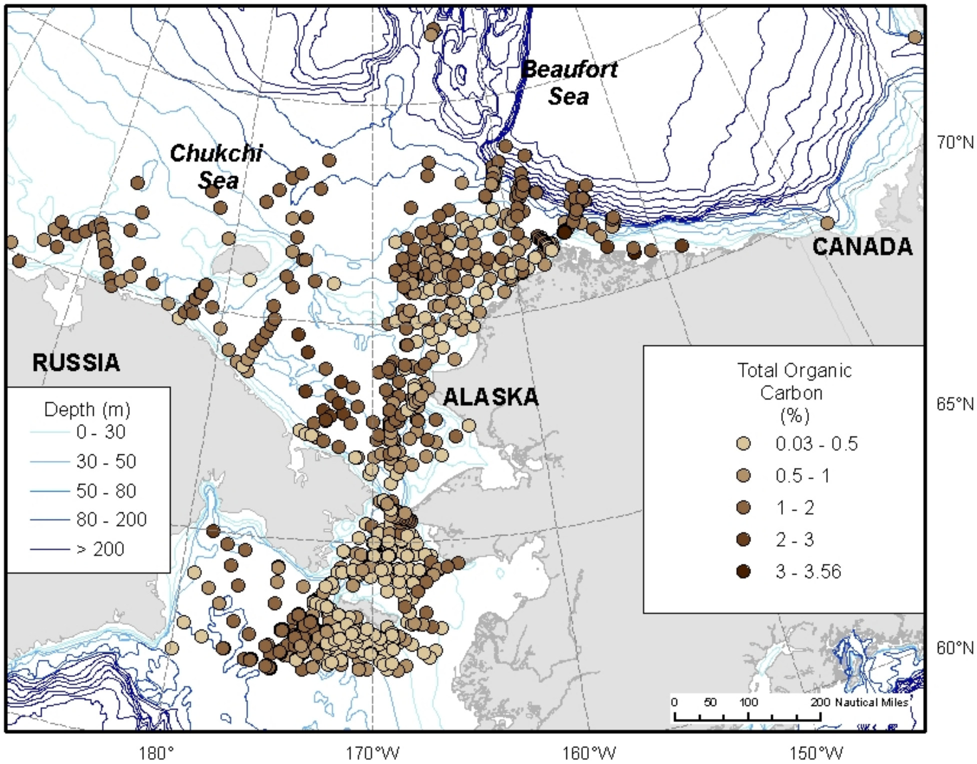


Figure C3.7 Distribution of surface sediment total organic carbon (TOC) content, 1974-2012 (point version).

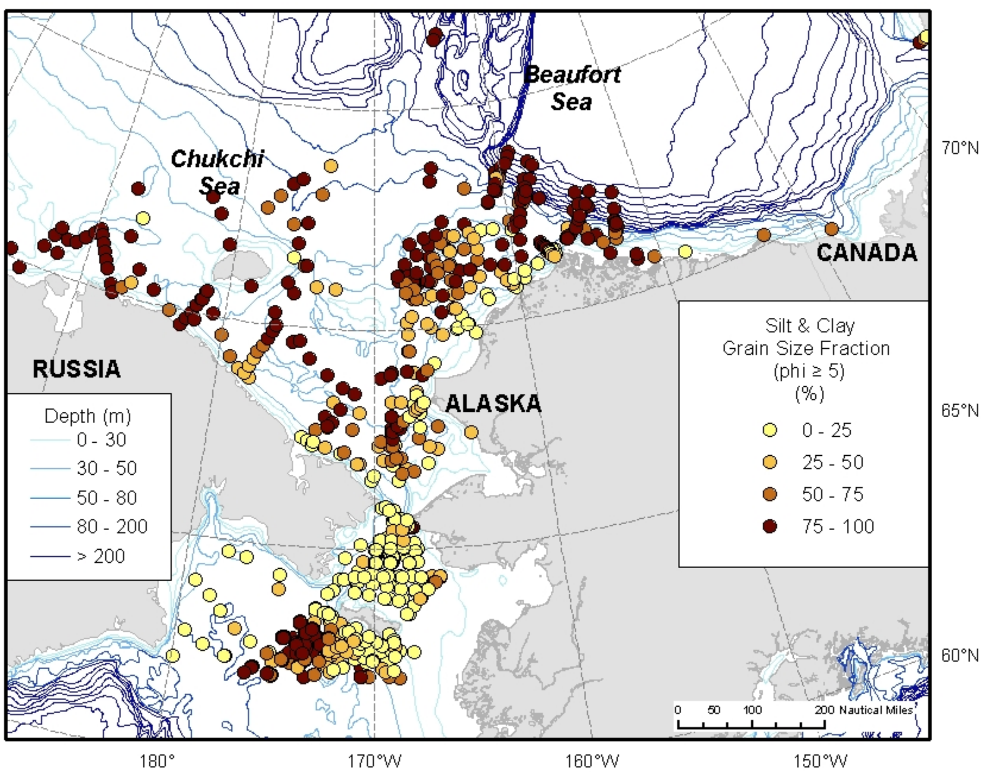


Figure C3.8 Distribution of surface sediment silt and clay (≥5 phi) content, 1974-2012 (point version).

Sediment community oxygen consumption (indicator of carbon supply to benthos) is used as an indicator of carbon supply to the underlying benthos. As part of PacMARS we have provided a multi-decadal composite of data that can be used to evaluate pelagic-benthic coupling and carbon cycling, in addition to investigating key drivers for the benthic system (Fig. C3.9). We are using these biological and rate measurements in a network modeling activity lead by Bob Ulanowicz (see Appendix G6 for details).

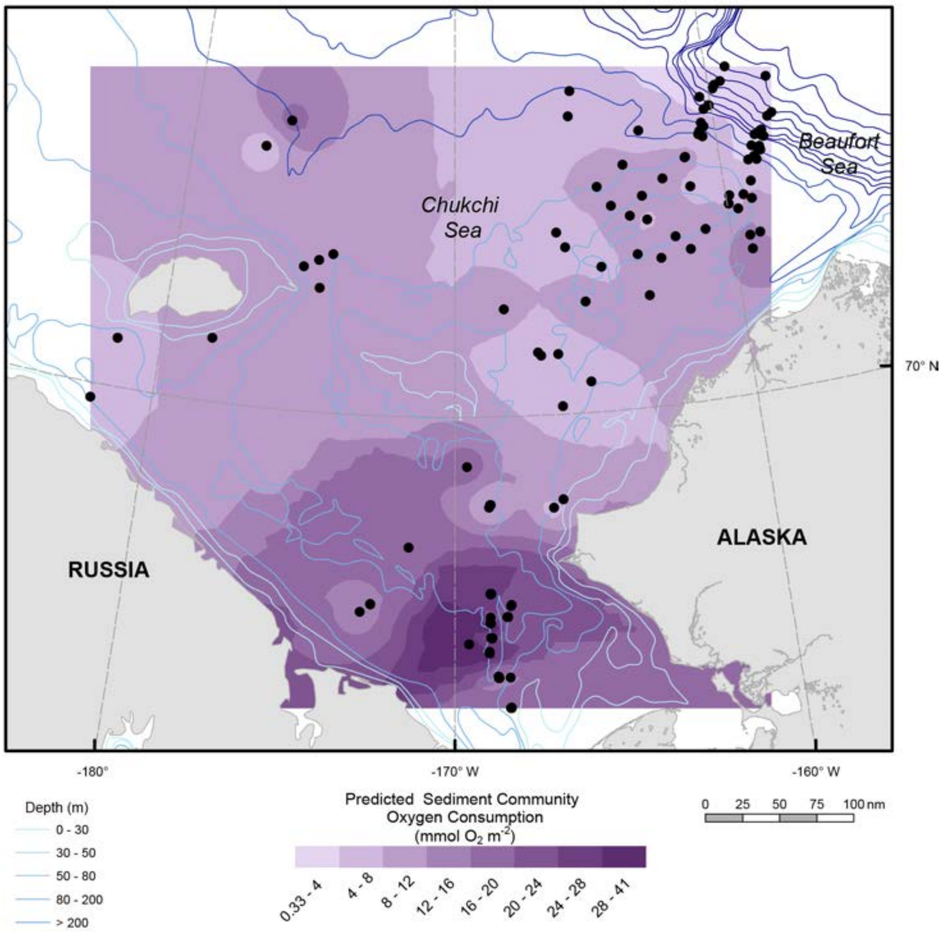


Figure 3.9. Distribution of sediment community oxygen consumption (mmol $O_2/m^2/d$) from 2000-2012 in the Chukchi Sea (updated from Mathis et al. 2014).

C3.3 Bottom water nutrients

Since bottom water nutrient values can be indicative of water mass characteristics, we have plotted the bottom water concentrations of nitrate+nitrite, ammonium, phosphate and silica for the period of 2000-2012 as an example of synthesis products being used to evaluate water mass characteristics and biological communities available (Fig. C3.10). All nutrients are present at the highest concentrations in the Anadyr water mass in the western part of the ecosystem from the northern Bering Sea through the Chukchi Sea. Notably, we can track Pacific water in the Anadyr stream transiting northwest through Bering Strait, down Barrow Canyon, and this water mass is observable on the slope of the Chukchi Sea. A factor that is imperfectly understood and could be studied in the future is the role of nutrient effluxes from the sediments in maintaining high nutrient values during the northward transit of Pacific water. These regenerated nutrients are available for mixing to surface waters for use in primary production when sunlight is sufficient. A recent paper by Mathis et al. (2014) discusses these processes, and here, we also evaluate the temporal and spatial role of bottom water nutrients in relation to carbon export production and benthic carbon cycling using sediment oxygen uptake rates as a proxy.

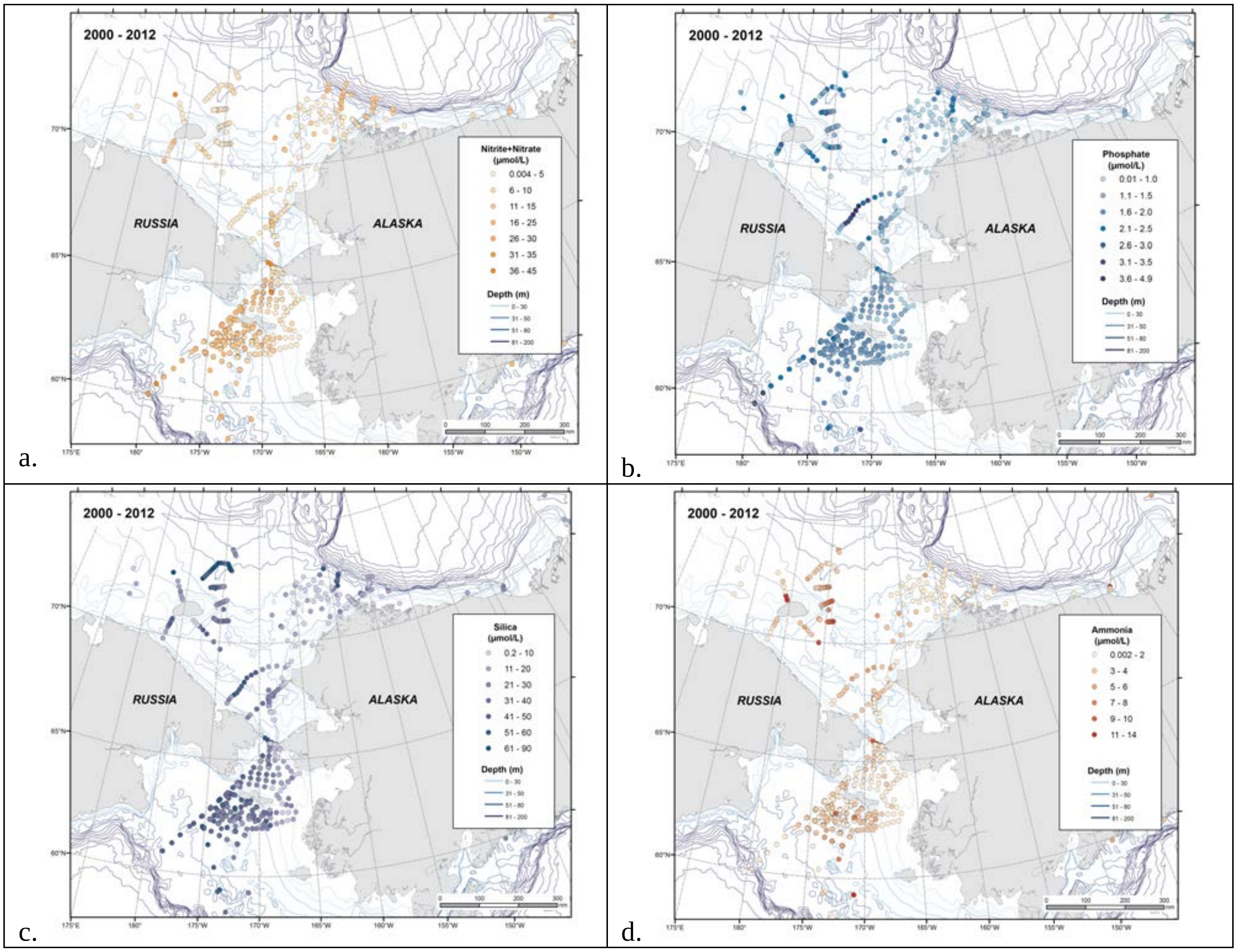


Figure C3.10 Distribution of bottom water nitrate+nitrite (a), phosphate (b), silica (c) and ammonium (d) in the Pacific Arctic region between 2000-2012 (data from Grebmeier/Cooper at the PacMARS EOL data site).

C4. Epifauna

C4.1 Epifaunal survey effort in the Pacific Arctic 1971-2012

Collections of epifaunal invertebrates have been conducted across the entire PacMARS area, but with varying gear types, during different decades in different areas, and with limited consistent resampling over time. First collections were made around Barrow (McGinnitie 1955) and the Project Chariot sudies in the 1950s (Sparks and Pereyra 1960), although information from these studies were not included in the data synthesis for several reasons. Specifically, McGinnitie (1955) listed and described species found at various locations, but did not describe benthic communities. The Sparks and Pereyra (1960) study provided ranks of species (e.g. common, rare etc.), but did not report actual numbers. Station locations were only shown graphically without coordinates. Spatially more extensive and (for the most part) more quantitative surveys of the entire epifaunal community have been conducted since the early 1970s, mostly from ship-based cruises with a total of over 20 surveys conducted in varying parts of the study area (Fig. C4.1, Table 4.1). Sampling has varied among regions with lowest effort in the Canada Basin, intermediate level efforts in the Northern Bering Sea and the Beaufort Sea and highest effort in the Chukchi Sea, in particular the northeastern Chukchi Sea (Fig. C4.1, Table B4.1). Norton Sound is the only region with a

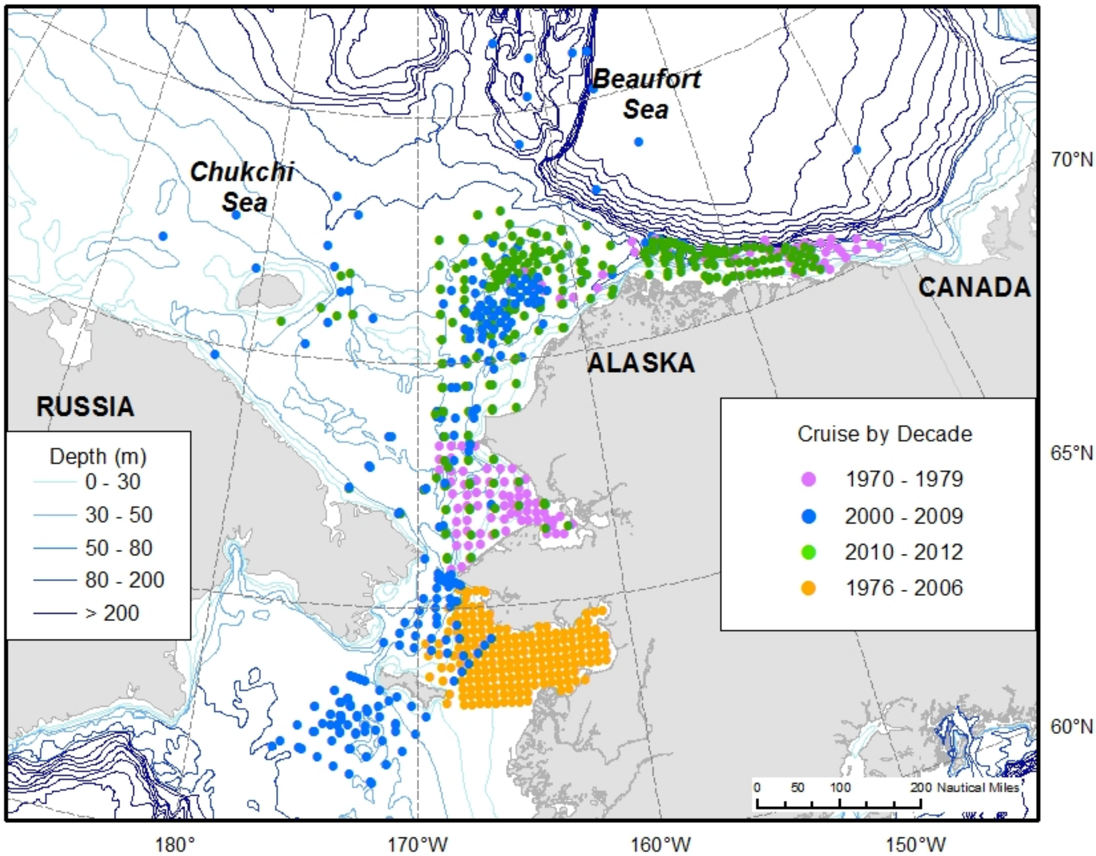


Figure C4.1 Overview of survey effort of epifaunal invertebrates from trawl hauls and photographic surveys from 1971-2012 a) by decade and b) gear type. Data sources listed in Table B4.1.

regular multi-decadal survey program conducted on a mostly triennial basis since 1976 (Hamazaki et al. 2005, Jewett et al. 2009). This survey is primarily undertaken as a management tool for maintaining the Norton Sound red king crab population that support the local commercial and subsistence fishery (http://www.fakr.noaa.gov/npfmc/PDFdocuments/membership/PlanTeam/Crab/May2013/NSRKC.pdf). No other area of the PacMARS area has a commercial harvest for any epifaunal invertebrates, so regular surveys are sparse. Survey effort was concentrated in the 1970s and post-2000 whereas effort was rather limited in the 1980s and 1990s. These surveys have primarily been motivated either by the interest in oil and gas exploration (e.g. Day et al. 2013), or by the need for resource assessment for potential future fisheries (e.g. Lauth 2011), or as part of ecosystem or climate studies (e.g. Bluhm et al. 2010).

Survey tools have not been consistent among epifaunal surveys and fell into three sets of gear types: otter trawls, beam trawls and video imaging tools. Otter trawls included large gear as used in the annual Eastern Bering Sea (EBS) trawl surveys for resource assessment (e.g. Lauth 2011), and much smaller otter trawls that can be operated from non-fisheries vessels (e.g. McKinney et al. 2012). Beam trawls have been used in the PacMARS area since 2004 with reasonably consistent mesh sizes and trawl duration (Table B4.1 in the methods section). Imaging methods deployed in the PacMARS area included high-resolution images and video. Net mesh sizes across all used nets varied substantially from 4-89 mm in the cod and from 7-89 mm in the body of the net. As with any other gear, mesh size (and haul speed) determines the size range of the organisms caught. Small mesh nets obviously retain small-bodied fauna that, collectively, contribute substantially to total epifaunal biomass (Fig. C4.2; also comparison in Rand and Logerwell 2011). Hauls made with small mesh, therefore, tended to result in higher abundance and

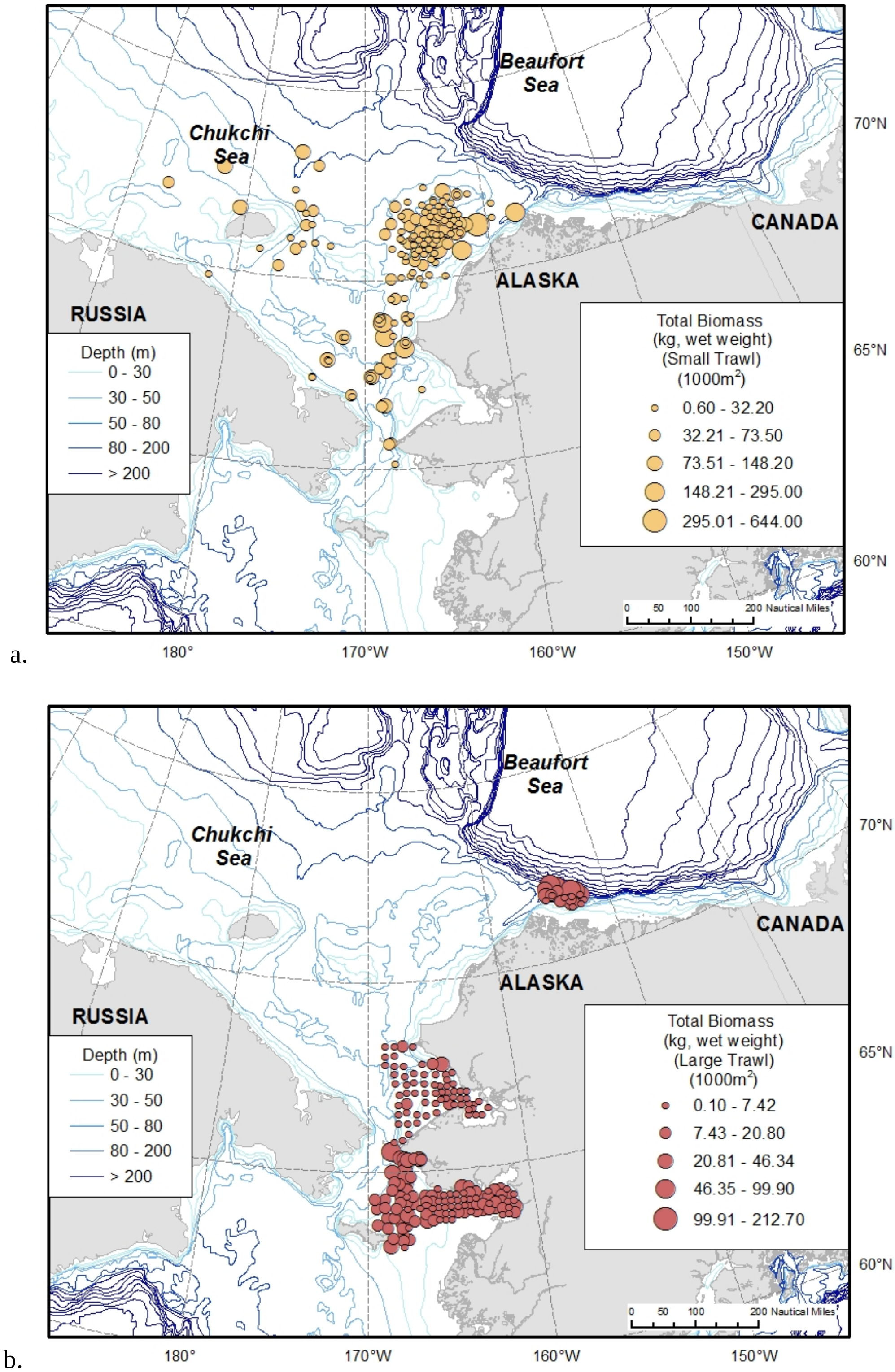


Figure C4.2 Distribution of epifaunal biomass from a. small mesh nets, and b. large mesh nets. Breaks using Jenks natural breaks. Note that the shelf break stations in the Beaufort Sea were fished with a small-mesh liner in the 83-112 net whereas the shelf stations were not. Data sources listed in Table B4.1.

biomass estimates than hauls made with large mesh (Figs. C4.2 and C4.3, Table B4.3). The difference in survey tools among studies limits region-wide comparisons, although differing net choices are understandable depending on the questions addressed. Studies using the large-mesh nets usually aim at creating data sets comparable to Eastern Bering Sea commerical trawl surveys and are conducted to facilitate identification and estimates of potential fishable resources. In our review we combined epifaunal abundance and biomass estimates from small-mesh net hauls in one set of figures and estimates from large-mesh net hauls in a separate set (Fig. C4.3 a,b).

Differences in estimates of taxon richness cannot be linked as clearly to net types, because taxonomic resolution varied among studies. Estimates presented here should be viewed as minima, because rare and difficult-to-identify taxa often are not identified to species level. An example are the Bryozoa (moss animals), which can add substantially to species richness (Sirenko 2001). New species discoveries were few among epifaunal invertebrates in recent decades but still occur (Chaban 2008, Sirenko 2009). Undescribed species were more frequent among the smaller benthic fauna, at the lesseer known continental slope, and in the Canada Basin (e.g. Gagaev 2008, 2009) and around the Aleutians (Clark and Jewett 2010).

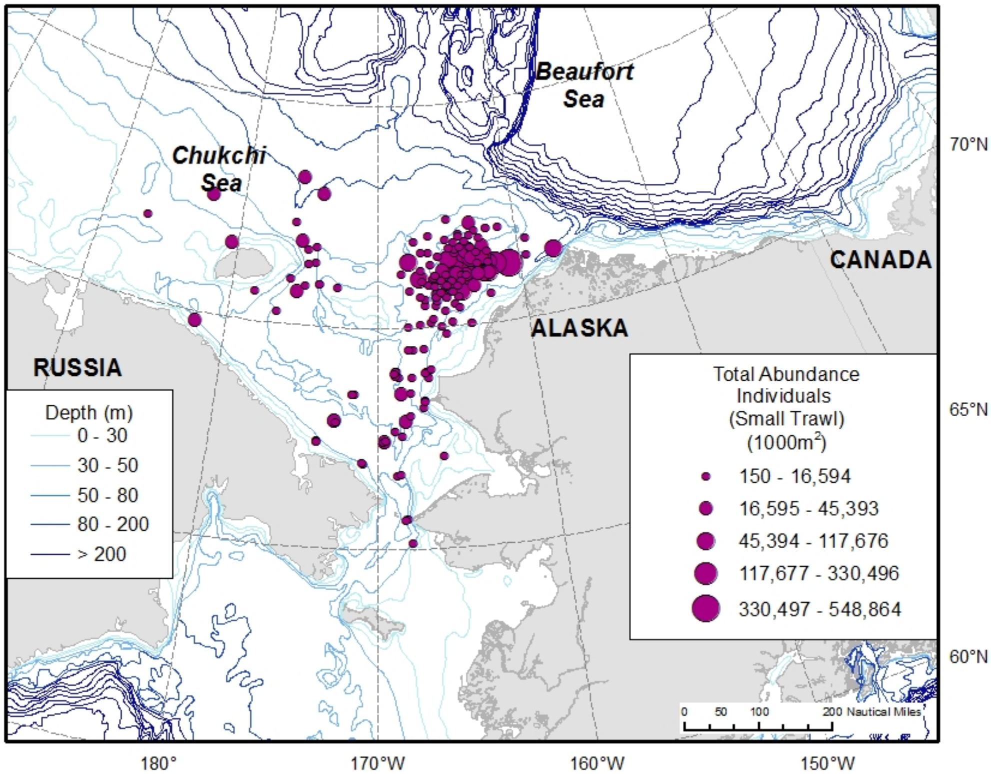
C4.2 Patterns in epifaunal abundance, biomass and taxon richness

Generally, biomass of epifaunal invertebrates ranged widely over about three orders of magnitude (Table C4.3, Fig. C4.3 a,b). There was little spatial overlap in the data available between large and small mesh hauls and a region-wide coherent pattern is still hard to discern, but a few patterns stand out (Fig. C4.2). Biomass peaked in the eastern Chirikov Basin, near Point Hope, at some locations in the northeastern Chukchi and at the western Beaufort Sea slope (Feder et al. 2006, Bluhm et al. 2009, Blanchard et al. 2013, Ravelo and Konar in prep.). The elevated biomass levels near and just southeast off Point Hope are in part due to relatively coarse bottom substrate supplying attachment for a biomass-rich filter-feeding community dominated by ascidians, in addition to sea stars and other taxa (Feder et al. 2005, Bluhm et al. 2009). In the northeastern Chukchi, locations with highest biomass were in depositional areas where brittle stars, *Ophiura sarsii*, predominated (Blanchard et al. 2013, Ravelo et al. 2014). At the western Beaufort Sea slope, elevated biomass is interpreted as a downstream effect of the outflow of nutrient-rich water through Barrow Canyon some of which gets deflected toward the east (Nikolopolous et al. 2009). This biomass was dominated by *C. opilio* and *O. sarsii* (Rand and Logerwell 2011, Ravelo and Konar in prep.).

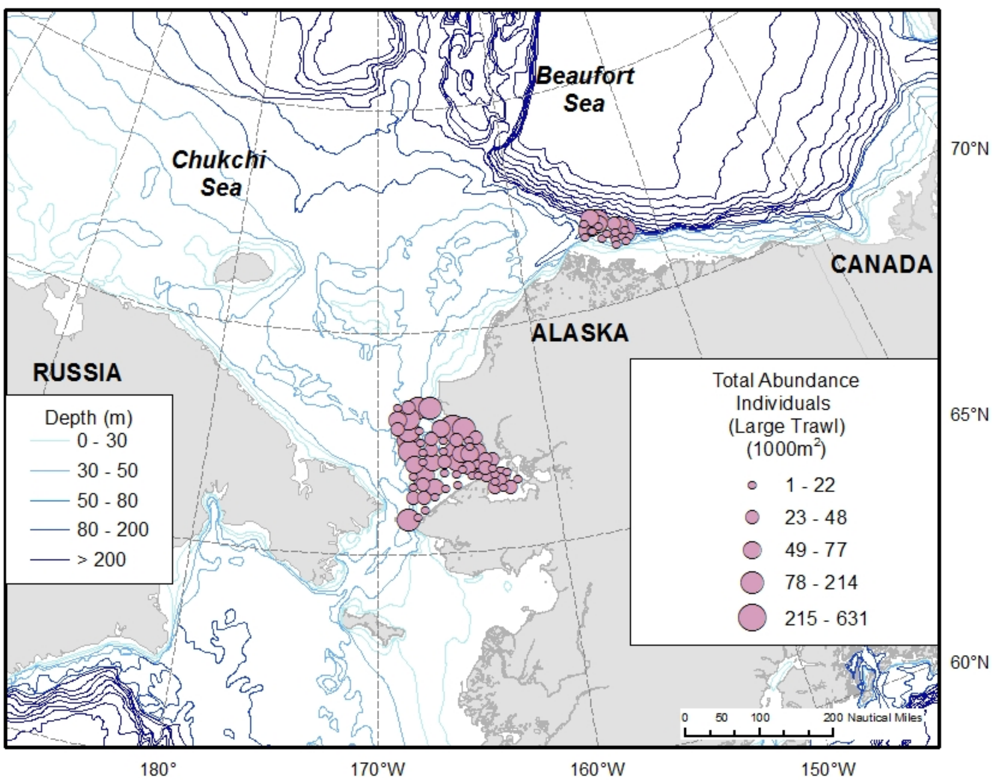
Table C4.3 Ranges of epifaunal abundance, biomass and taxon richness measured by small mesh and large mesh trawl hauls. Data sources listed in Table B4.1.

	Mesh	**Abundance (ind 1000 m^{-2})**	**Biomass (kg wet wt 1000 m^{-2})**	**Taxon count**
Minimum	large	0.9	0.1	6
	small	31	0.6	1
Maximum	large	631	213	90
	small	548864	644	63
Mean	large	51	16	30
	small	29945	49	23
SD	large	95	27	11
	small	63904	67	10
Median	large	31	9	28
	small	5876	23	22

Epifaunal biomass patterns can be dominated by a single species such as the brittle star *Ophiura sarsii* or the snow crab *Chionoecetes opilio* (Frost and Llowry 1983, Bluhm et al. 2009, Rand and Logerwell 2011, Blanchard et al. 2013). *Ophiura sarsii* and other characteristic soft bottom taxa such as *Ctenodiscus*



a.



b.

Figure C4.3 Distribution of epifaunal abundance from a. small mesh nets, and b. large mesh nets. Breaks using Jenks natural breaks. Data sources listed in Table B4.1.

crispatus in the northwestern Chukchi Sea are relatively immobile and indicators of soft bottom depositional areas with high vertical carbon flux (Blanchard et al. 2013). *C. opilio*, in contrast, undergoes ontogenetic migrations in other areas (Ernst et al. 2005). Considerable recruitment variability exists between years (Zheng and Kruse 2006), thereby diluting local pelagic-benthic coupling.

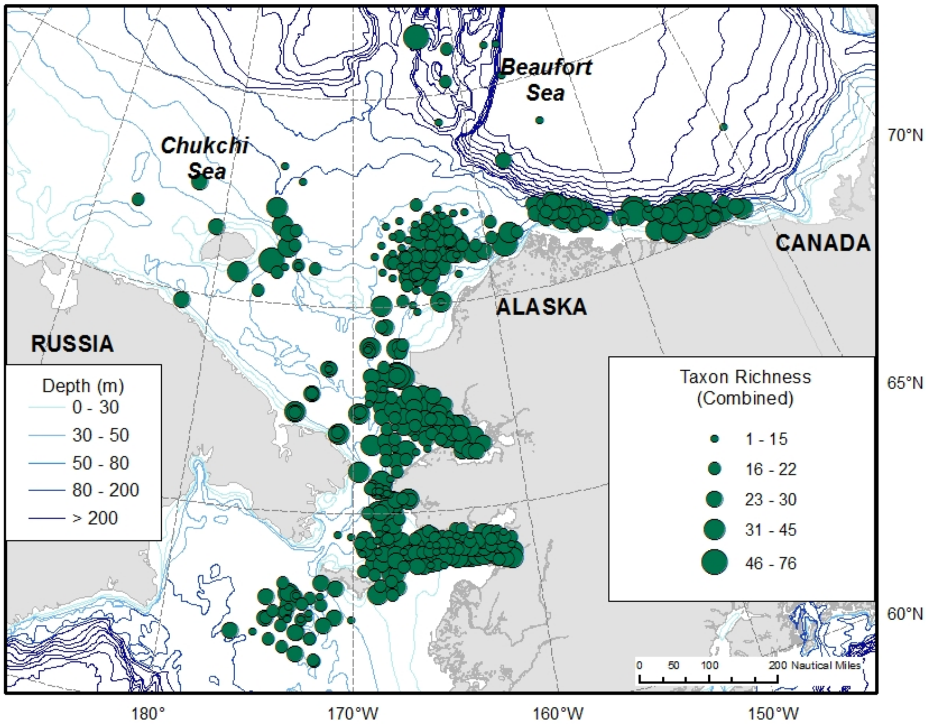
The PacMARS-wide distribution of epifaunal species richness as depicted in Fig. C4.4 should be interpreted with caution because of bias by varying levels of taxonomic resolution among studies. A few preliminary observations are noteworthy, although they should be investigated more rigorously:

Locations with coarse bottom substrate tend to have high epifaunal species richness, for example Barrow and Herald Canyon, and the area off Point Hope. Sessile substrate-attached taxa such as sponges, ascidians, and bryozoans are present and/or more species rich here than elsewhere (e.g. Feder et al. 2005, Bluhm et al. 2009). In contrast, the more central and soft bottom dominated areas of the Chukchi Sea appear to have comparatively lower epifaunal taxon richness. The (Eastern) Beaufort Sea slope fauna also appears to have high epifaunal diversity. Although not obvious in species numbers, biogeographic composition changes across the PacMARS region with a higher proportion of Pacific species in the south, and a higher contribution of Arctic species in the North (Dunton 1992 and references therein, Bluhm et al. 2009). The deep areas of the slopes and the Canada Basin are dominated by fauna resembling today's Atlantic deep-sea fauna because of the lacking deep connection to the Pacific and the stenobathic distribution of the Pacific fauna in the Chukchi Sea (Bluhm et al. 2011 and references therein).

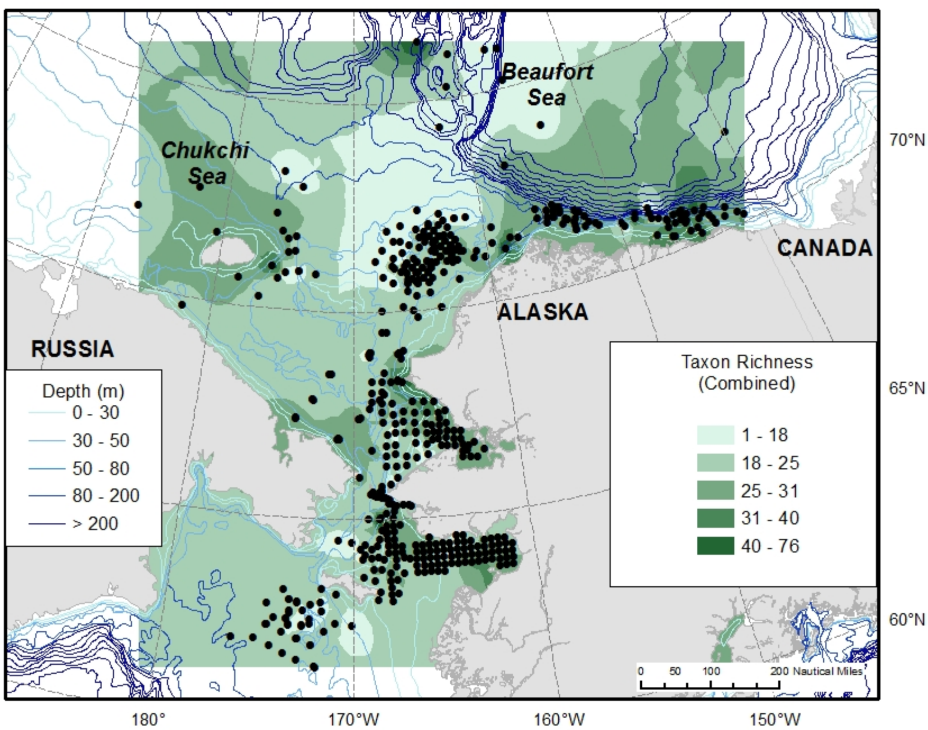
The integrated nature of the PacMARS effort will allow evaluation of correlations between different ecosystem components in the Pacific Arctic. As an example, we can evaluate the contributions of infauna and epifauna to total benthic biomass. The emerging epifaunal biomass pattern shows some similarities and some differences to that of the better-surveyed infauna. The latter reaches biomass maxima in the southwestern and northeastern Chukchi Sea include Barrow Canyon, the Chirikov Basin and southwest of St. Lawrence Island (Grebmeier 2012 and this report). In an exploratory analyses of 55 locations sampled synchronously for epifaunal and infaunal biomass in the Chukchi Sea between 2004 and 2010, epifauna contributed on average 21% to combined benthic biomass with a range of <1 to 89%. The relationship between epifaunal and infaunal biomass at these sites revealed no obvious pattern (see also Bluhm et al. 2009). Finally, estimates of contributions of meiofaunal and bacterial biomass to total benthic biomass are generally unavailable.

C4.3 Variability and change

Variability or change in epifaunal communities is difficult to document because limited overlap exists in space or gear type of epifauna sampling in the Pacific Arctic since sampling began in the 1970s (Table B4.1). As mentioned earlier, the only significant exception is the triennial red king crab trawl survey in Norton Sound since 1976. This time-series has documented a biomass increase of total catch per unit effort (biomass) including invertebrate fauna since 1976, with some variability in trend between years (Fig. C4.5; Hamazaki et al. 2005, Jewett et al. 2008). The biomass increase is primarily due to increases in the sea star *Asterias amurensis* (ibid.). Changes in invertebrate biomass were related to the duration of the ice-free period and incident solar radiation in the area as well as the Pacific-North American Index, whereas bottom temperatures did not significantly change (Jewett et al. 2008). Species composition did not change over time. The annual bottom trawl surveys conducted in the eastern Bering Sea (EBS) by the Alaska Fisheries Science Center has included the northern Bering Sea including the Chirikov Basin during 4 survey years since 1985 (http://www.afsc.noaa.gov/RACE/groundfish/survey_data/data.htm), but we are unaware of any temporal analysis that has been completed. Analyses of annual EBS survey data (south of the PacMARS study area) documented community-wide northward distribution shifts of fish and crab stocks (Mueter and Litzow 2008). In areas previously covered by the EBS cold pool, biomass, taxon richness and average trophic level increased over time and these changes were associated with indicators of climate warming (ibid). Warming of near-bottom water temperatures in the southern



a.



b.

Figure C4.4 Distribution of epifaunal taxon richness from all nets combined as a) scaled circles (using Jenks natural breaks) and b) interpolated through inverse distance weighting. Data sources listed in Table B4.1.

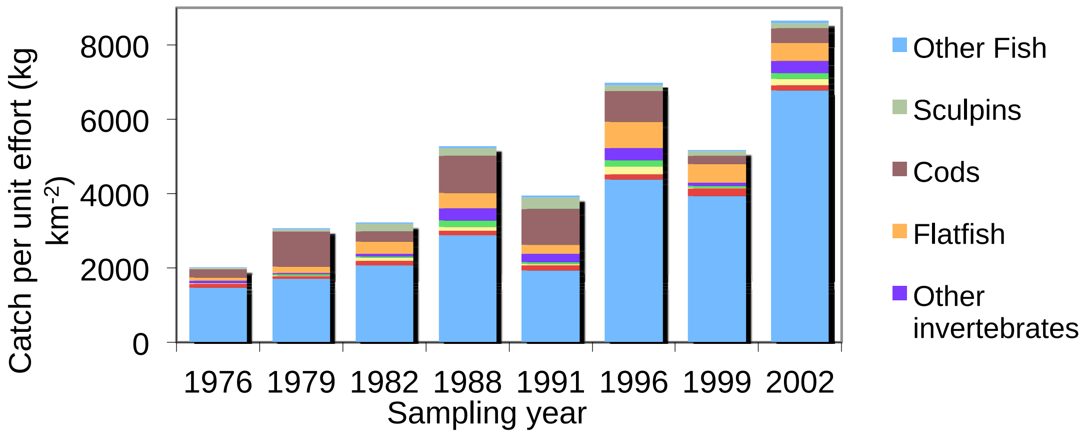


Figure C4.5 Biomass (kg km^{-2}) of Norton Sound trawl fauna between 1976 and 2002 in triennial trawl surveys. Data from Hamazaki et al. 2005 and Jewett et al. 2009.

Bering Sea was followed, with a 6-year time lag, by a contraction to the north of mature female *C. opilio* distribution range (Orensanz et al. 2004). Northward distribution range shifts were also described for a few individual epifaunal species (Sirenko and Gagaev 2007), although skepticism has been expressed because of poor knowledge of historical distribution patterns (Blanchard et al. 2013).

Solid multi-decadal time series studies of epibenthic invertebrate communities in the Chukchi and Beaufort Sea have not been accomplished. A few sites in the southern Chukchi were sampled repeatedly with a small-mesh plumb staff beam trawl as in the NE Chukchi in 2004, 2009, and 2012 during RUSALCA cruises (http://www.arctic.noaa.gov/aro/russian-american/). Since 2008, repeat stations were also sampled in the northeastern Chukchi Sea with the same beam-trawl during the CSESP and COMIDA projects (Blanchard et al. 2013, Ravelo et al. 2014).

In the northeastern Chukchi Sea comparable surveys using the same 83-112 trawl net employed for the annual EBS trawl surveys were conducted in 1994 and again in 2012 (Barber et al. 1997, Arctic Eis https://web.sfos.uaf.edu/wordpress/arcticeis/?page_id=205). For all Chukchi Sea surveys, temporal comparisons are ongoing.

C5. Food Webs: Lower Prey-Based Trophics and Selected Links to Higher Trophic Levels

Our synthesis of food web structure is based on stable isotope methodologies that employed an extensive data set of primary producer and consumer isotopic values extending over large spatial and temporal scales. Generally, carbon isotope ratios are used as an indicator of ultimate carbon sources because of the small heavy-isotope enrichment steps between consecutive consumers (0-1‰), while nitrogen isotope ratios are used as indicators of trophic level (TL) because of larger heavy-isotope enrichment (3-4‰) between successive TLs. Together, both values can provide important information insights on the assimilation and transfer of organic matter by organisms.

The significant step-wise enrichment of nitrogen isotopic ratios between consumers and their prey, along with information that identifies their ultimate sources, provides a unique opportunity to examine regional differences in food web structure and the relative importance of different sources of carbon in the western Arctic. Our synthesis is focused on the on lower trophic level species, particularly the invertebrate prey of marine mammals, birds, and fish. Our analysis also provides selected coverage on the foraging responses of walruses and gray whales to benthic food availability and a concise summary of isotope-based demersal fish trophic dynamics.

The data used here are archived as ArcGIS stable isotope shapefiles separated by species: “Animalia.txt” contains taxa, “stable_isotope_synthesis_metadata.xml” holds the FGDC metadata, and "Stable Isotope Data.lyr" is a layer file in the EOL map server for visualizing the distribution of data.

C5.1 Carbon sources

This new compilation of stable isotopic data examines portions of the western arctic lower trophic food web, extending north from the Bering Strait into the Chukchi Sea, west into the East Siberian Sea to Chaun Bay, and eastward along the coast and shelf of the Beaufort Sea to Banks Island in Canada (Fig.C5.1). The west to east trend in ^{13}C depletion is consistent with proportionally higher terrestrial organic carbon contributions and is not only observed in sediments (Fig. C5.1), but also in particulate organic matter (POM; Fig. C5.2), zooplankton (Fig. C5.3; see also Saupe et al. 1989), benthic fauna (Figs. C5.4a-b; see also Dunton et al. 1989), and arctic cod (Figs. C5.4c). Schell et al. (1989) also noted isotopic changes in seasonally sensitive tissues of bowhead whales that migrate through the region that was consistent with this trend. In marked contrast to the Chukchi-Bering ecosystem to the west and the Queen Elizabeth Islands to the east, the Beaufort Sea is clearly estuarine in character because of enormous freshwater contributions from local runoff and major rivers, including the Colville and Mackenzie (Macdonald et al. 2004, McClelland et al. 2006).

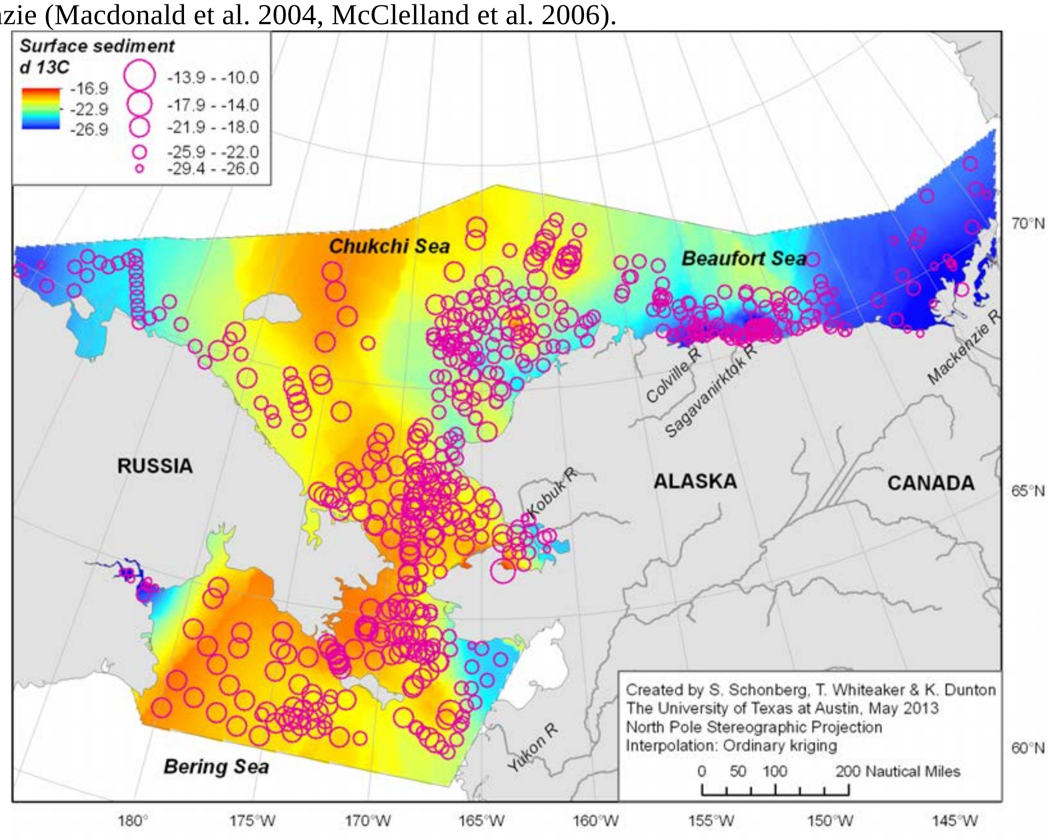


Figure C5.1 Variation in the distribution of δ^{13}C values for surface sediments across the western arctic coast and shelf region. The most ^{13}C-depleted sediments are found at river mouths and eastward along the Beaufort Sea coast.

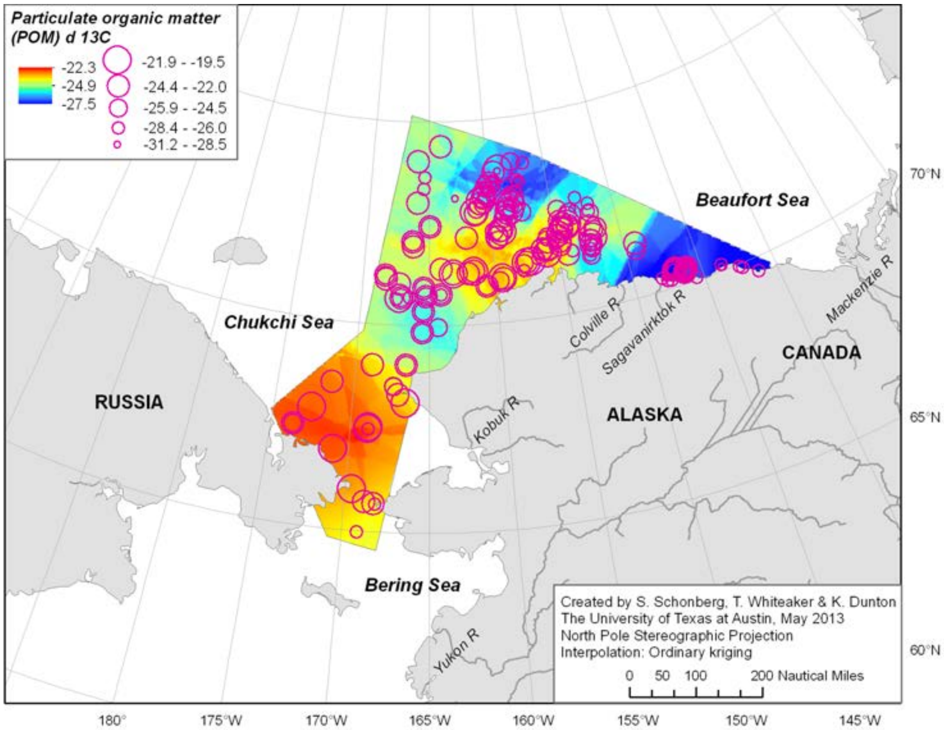


Figure C5.2 Particulate organic matter (POM). Distribution and range of $\delta^{13}C$ values (‰).

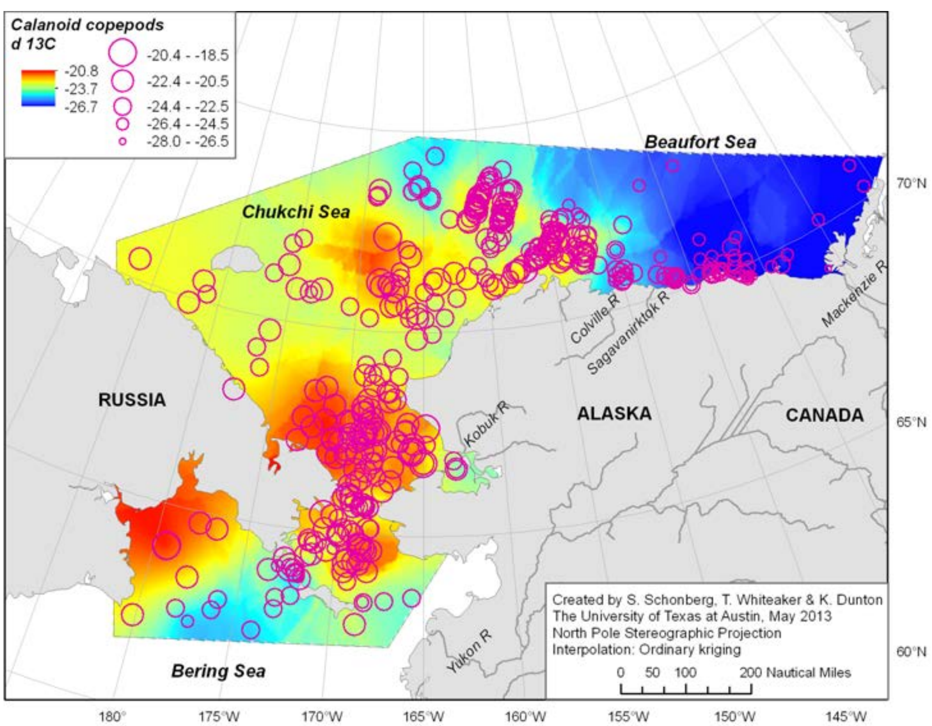
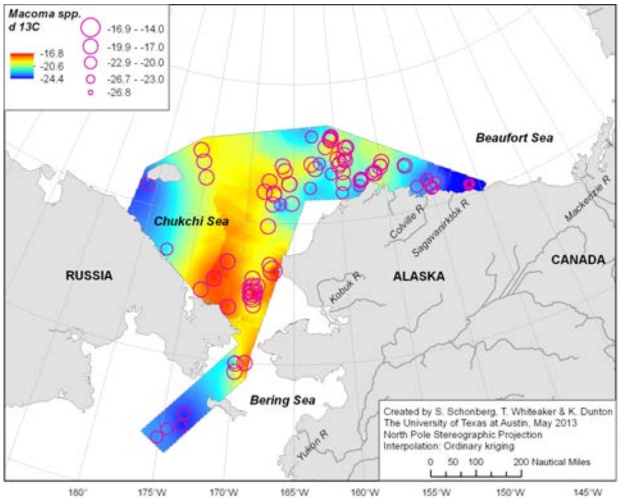
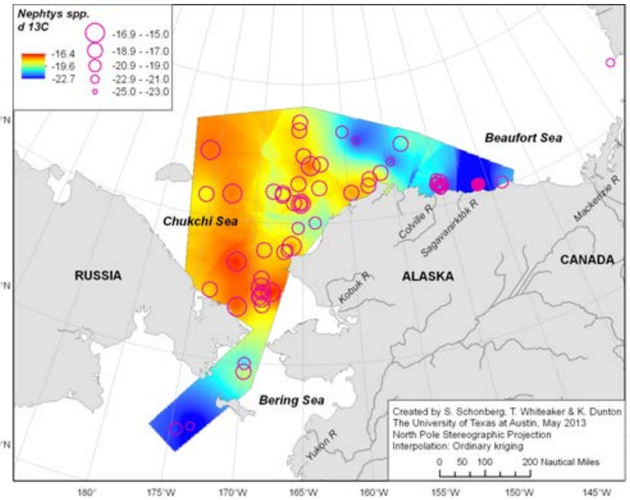


Figure C5.3 Distribution and range of $\delta^{13}C$ values (‰) of calanoid copepods.



a.



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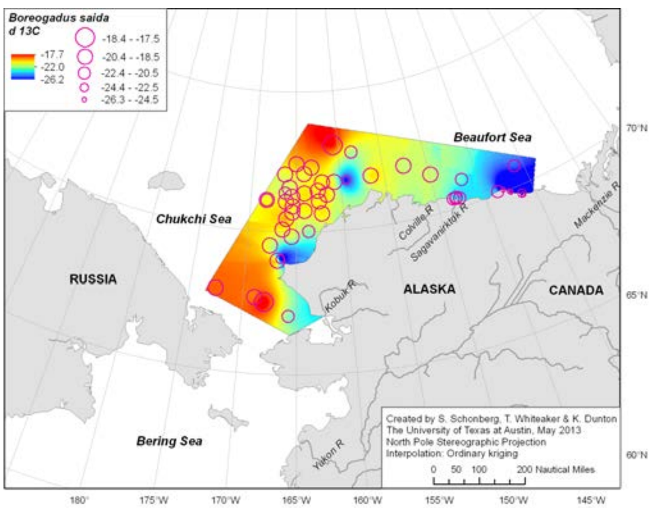


Figure C5.4 Distribution and range of $\delta^{13}C$ values (‰) for benthic fauna, including a. *Macoma* spp. (bivalve), b. *Nephtys* spp (polychaete), and c. *Boreogadus saida* (Arctic cod).

c.

C5.2 Pelagic fauna

Variations in organism trophic level, both geographically and in frequency, are presented for six representatives of the pelagic food web, in order of trophic ascendency (Figs. C5.5a-d). The tiny calanoid copepod *Eucalanus* clearly occupied the lowest trophic level (1.6 - 2.0), followed by *Calanus glacialis* and the euphausiid *Thysanoessa* (1.6 - 3.0), *Calanus hyperboreus* (2.1 - 3.0), the zooplankton chaetognath predator *Sagitta* (3.1-4.0), and the arctic cod *Boreogadus saida* (2.6 - 4.0) (Fig. C5.6). Larger ranges in trophic position, as exemplified by *Calanus glacialis*, reflect diversity in feeding behavior indicative of an organism that feeds at a multitude of trophic levels, or in the case of these lower trophic pelagic species, the shifts may be driven by variation in ^{15}N POM values.

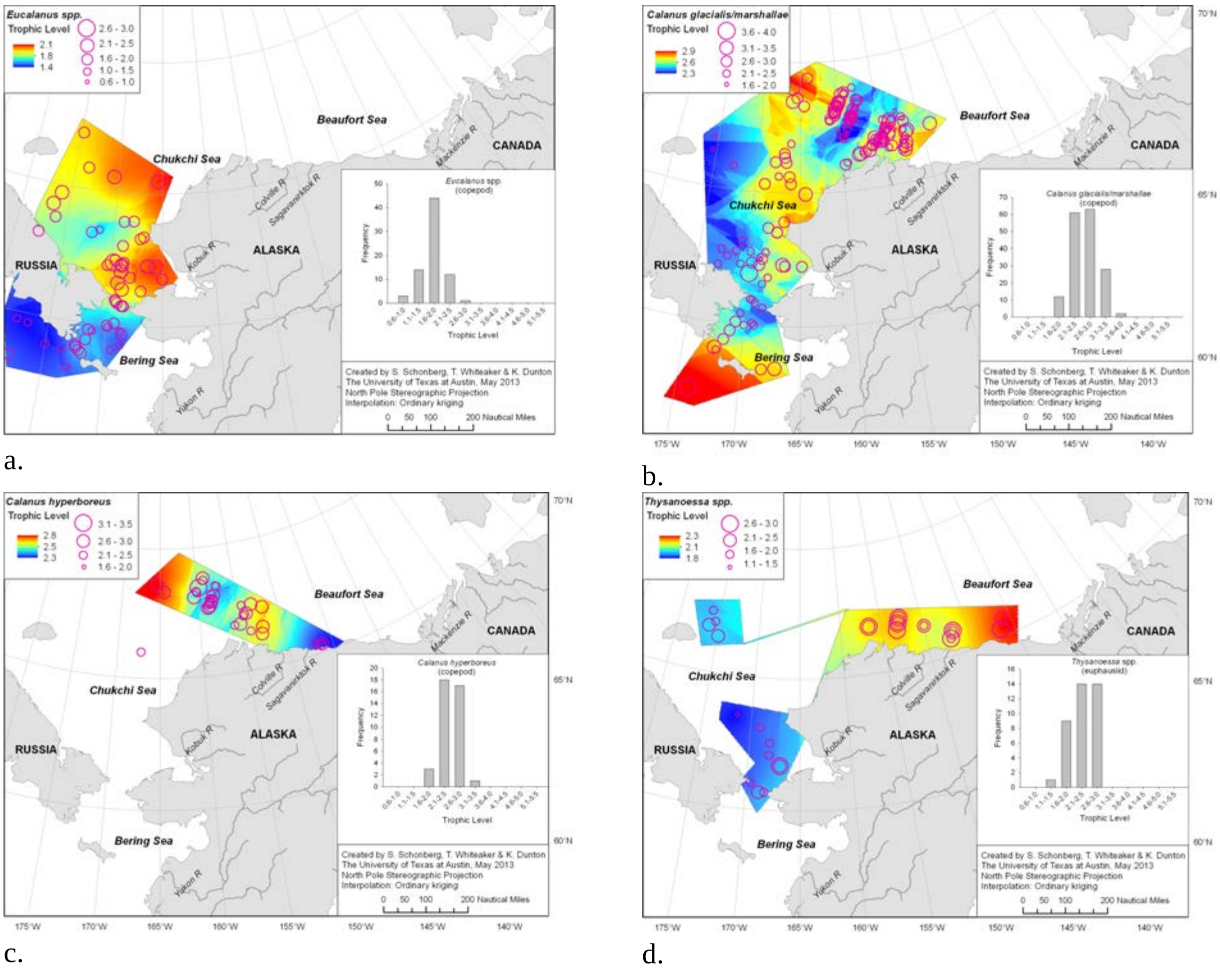
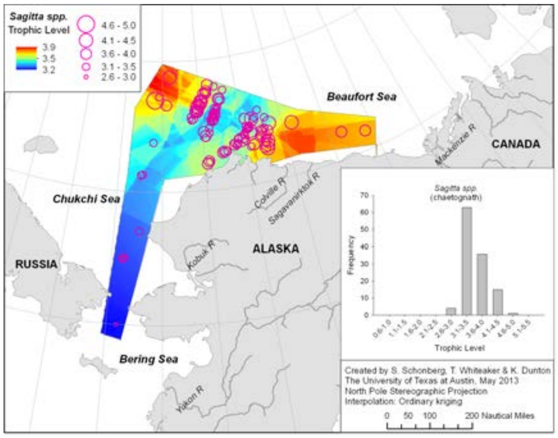


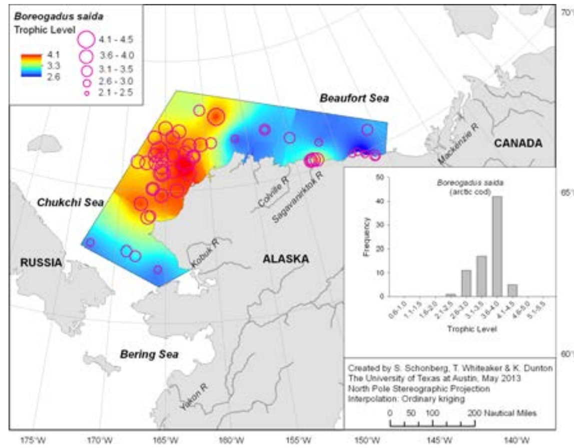
Figure C5.5 Variation in trophic level (TL) for pelagic copepods, including a. *Eucalanus* spp., b. *Calanus glacialis/marshallae*, c. *Calanus hyperboreus*, and euphausiids, including d. *Thysanoessa* spp., all analyzed in the PacMARS study area. Frequency distribution of predicted trophic level for each organisms based on $\delta^{15}N$ analyses depicted in lower right inset.

C5.3. Benthic fauna

Variations in organism trophic level were pronounced in the benthic consumers, broadly reflecting their strong opportunistic feeding behavior and dependence on a variety of carbon sources of both marine and terrestrial origin. We present data here for twelve representatives of the infaunal and epibenthic system (Figs. C5.7a-d, C5.8a-d, and C5.9). Four bivalves (*Yoldia, Macoma, Nuculana,* and *Ennucula)* occupy the lowest trophic levels throughout the western arctic study area (predominant range, 1.6 – 2.5). *Astarte* spp. appear to occupy higher trophic levels based on values ranging from 1.6 to 3.5 and is seems far more variable. Similarly, four polychaetes (*Sternaspis, Nephtys, Scoletoma, and Maldane sarsi*) have trophic level indices ranging from 2.1- 4.0, indicative of multiple linkages to a variety of food sources. The ophioroid *Ophiura sarsi* displays a wide range in trophic position (2.6 – 4.5), likely a product of its consumption of benthic microalgae, meiofauna, and detrital particles, although highest trophic level values are west and north of the Alaskan coast (Fig. C5.9). The snow crab *Chionoecetes opilio*) clearly occupies the third trophic level (3.6 – 4.0), with the food web at the highest level with the gastropod predator *Neptunea* spp. (3.6 - 5.0).

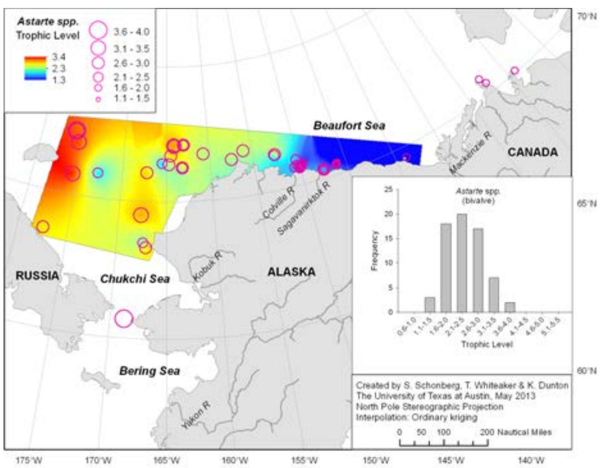


a.

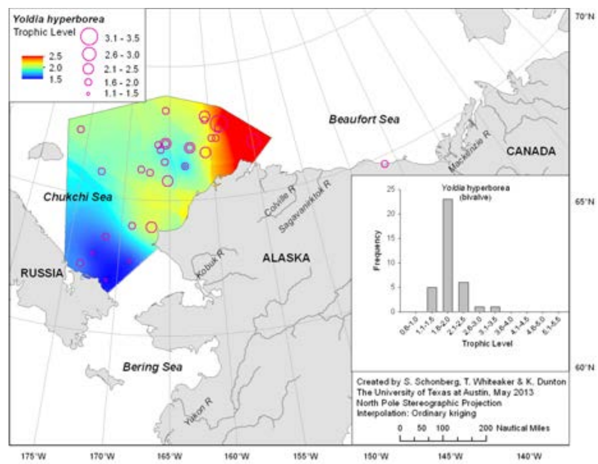


b.

Figure C5.6. Variation in trophic level (TL) for the pelagic consumers a. *Sagitta* spp. (chaetognath or arrow worm) and b. *Boreogadus saida* (arctic cod) analyzed in the PacMARS study area. Frequency distribution of predicted trophic level based on $\delta^{15}N$ analyses depicted in lower right inset.



a.



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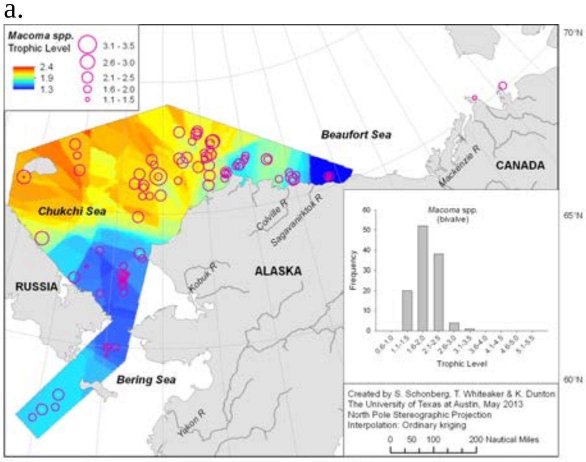

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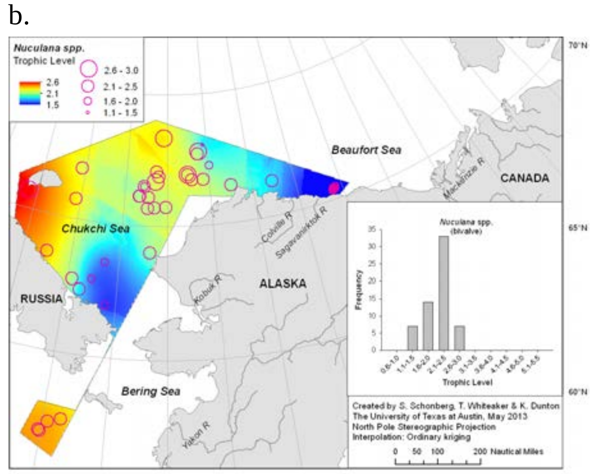


d.

Figure C5.7 Variation in trophic level for infaunal bivalve consumers, including a. *Astarte* spp., b. *Yoldia hyperborean*, c. *Macoma* spp., and d. *Nuculana* spp. Frequency distribution of predicted trophic level based on $\delta^{15}N$ analyses depicted in lower right inset.

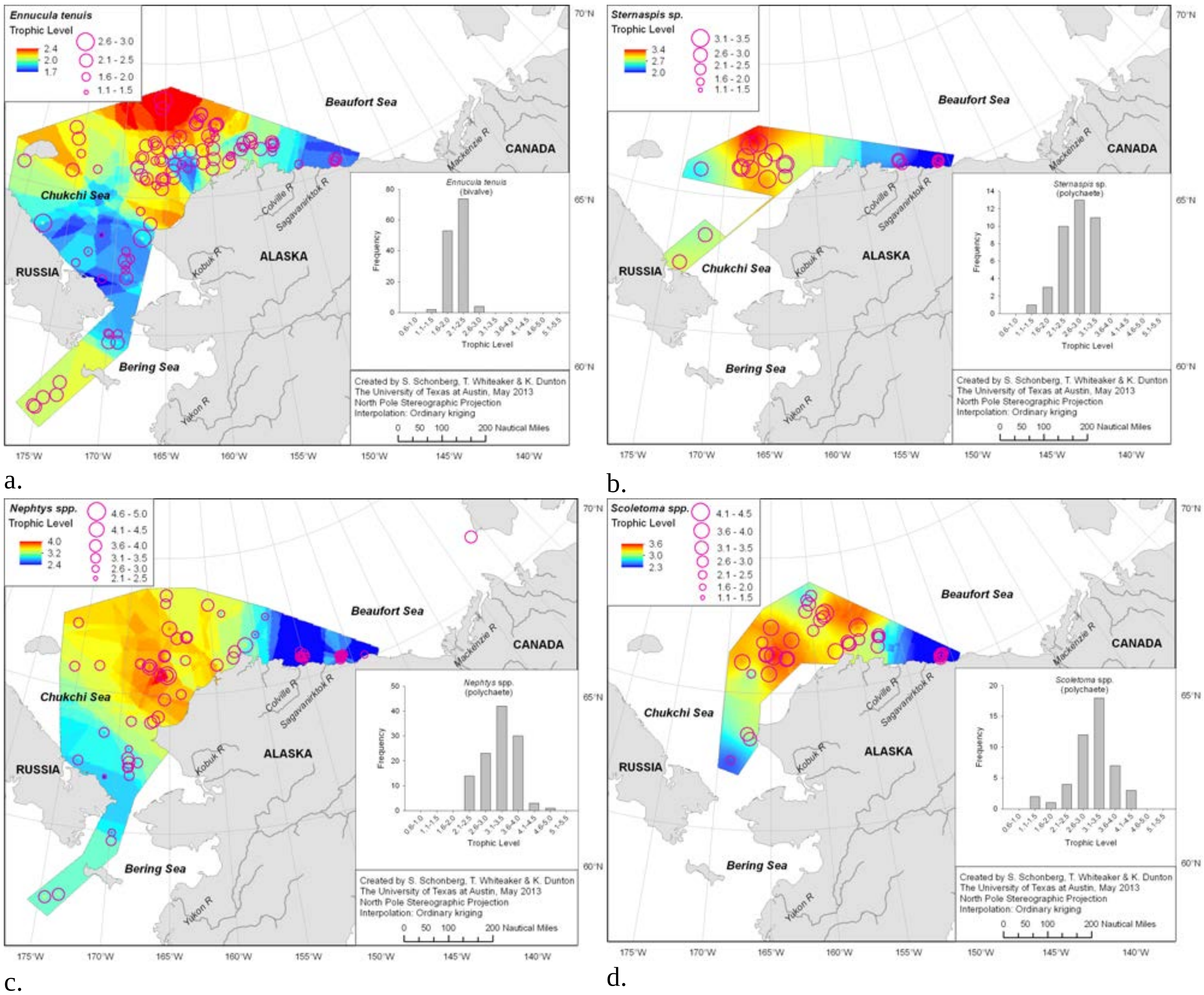


Figure C5.8 Variation in trophic level for infaunal consumers, including a. *Ennucula tenuis* (bivalve), b. *Sternaspis* sp. (polychaete), c. *Nephtys* spp. (polychaete), and d. *Scoletoma* (polychaete). Frequency distribution of predicted trophic level based on $\delta^{15}N$ analyses depicted in lower right inset.

C5.4 Conceptual food web model

We present two conceptual food web models for the western Arctic, one for a "gateway" arctic sea (e.g. Chukchi), the other for a marginal interior Arctic Ocean shelf (e.g. Beaufort). For the Chukchi (Fig. C5.10), McTigue and Dunton (2013) recently provided evidence to support the importance of a potential link between the benthic microbial and the macrofaunal food webs in the Arctic as noted in other studies (McConnaughey and McRoy 1979, Lovvorn et al. 2005, Dunton et al., 2012).

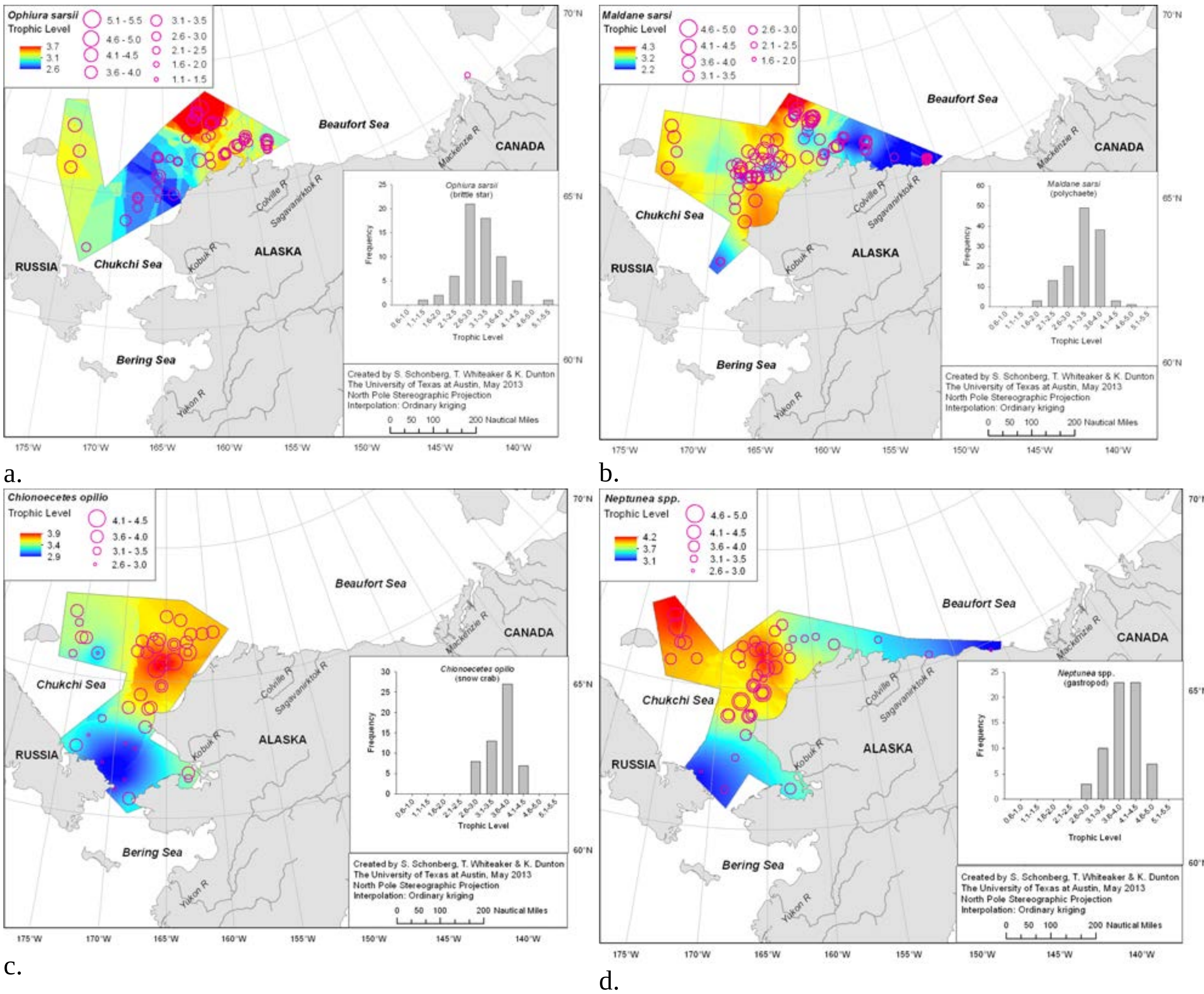


Figure C5.9 Variation in trophic level of for infaunal and epibenthic consumers, including a. *Ophiura sarsii* (brittle star), b. *Maldane sarsi (*polychaete*)*. c. *Chionoecetes opilio* (snow crab), and d. *Neptunea* spp. (gastropod). Frequency distribution of predicted trophic level based on $\delta^{15}N$ analyses depicted in lower right inset.

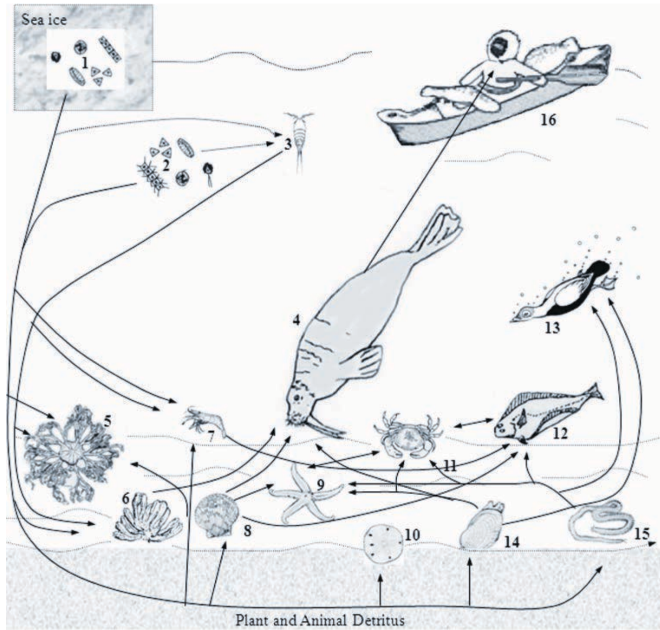


Figure C5.10 Conceptual representation of a simplified northern Bering/Chukchi Sea food web. The high abundance of benthic biota reflects the large proportion of phytoplankton that falls directly to the seabed, ungrazed by pelagic organisms. Arrows show the direction of energy transfer for marine algae, invertebrates, and fish based on available isotopic evidence. The direct assimilation of phytoplankton by the benthos results in shorter food chains and a more efficient transfer of carbon to large marine mammals and diving seabirds. Organisms: 1: ice algae; 2: phytoplankton; 3: copepods; 4: walrus; 5: basket stars; 6: ascidians; 7: shrimps; 8: filter-feeding bivalves; 9: sea stars; 10: sand dollars; 11: crabs; 12: bottom feeding fishes; 13: diving seabirds; 14: deposit feeding bivalves; 15: polychaetes, 16: native subsistence hunters.

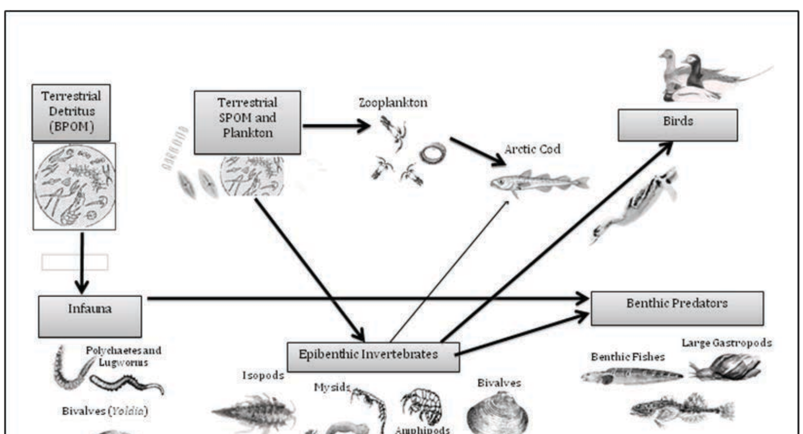


Figure C5.11 A conceptual model of a Beaufort Sea lagoon and coastal food web. Benthic biota receives both autochthonous (phytoplankton) and allochthonous (terrestrial) inputs of carbon. Arrows show direction of energy transfer. For arctic cod, which feed on prey in both the water column and benthos, the linkage to pelagic sources of energy is slightly stronger based on available isotope data. The diversity of the benthic fauna reflects a resilient ecosystem that serves as the base of a food web that supports a variety of critical prey item for seals and anadromous fishes on the Beaufort shelf.

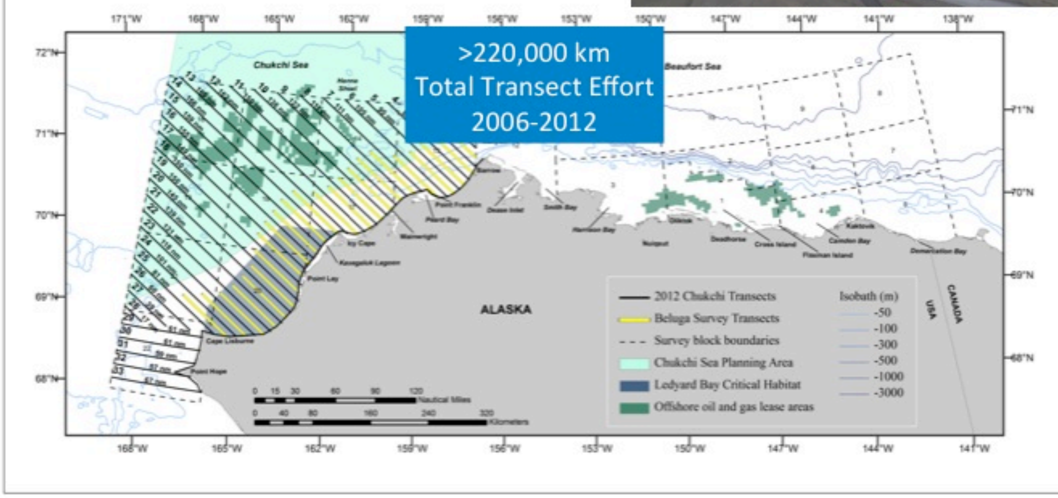
C5.5 Marine mammals in food web structures

There exist several higher trophic level studies associated with NOAA and BOEM funded efforts that have been used in PacMARS food web syntheses (Table C5.1). Use of these and other summary results from NOAA, BOEM and USFWS surveys in the SOAR effort are also discussed in Section A3. The spatial extent for these programs was presented at the PacMARS-SOAR Open Science Meeting in January 2013 (for an example, see Fig. C5.12).

Table C5.1 Higher-trophic data summary and web links and point of contact (POC) of data sources used for the PacMARS effort from US agencies and industry. Key: ArcEIS=Arctic Integrated Ecosystem Survey, ASAMM=Aerial Surveys of Arctic Marine Mammals, BOWFEST=Bowhead Whale Feeding Ecology Study, CHAOZ= CHukchi Acoustics, Oceanographic & Zooplankton Study, CSESP=Chukchi Sea Environmental Studies Program, EMA (BASIS)=Ecosystem Monitoring and Assessment (Bering-Aleutian Salmon International Survey**)**, NSF=National Science Foundation, SNACS=Study of the Northern Alaska Coastal System; see Appendix G1 for further descriptions of the individual programs and funders.

Source	**Acronym**	**Web link and Point of Contact (POC)**
Marine Fishes & Oceanography	EMA (BASIS)	http://www.afsc.noaa.gov/ABL/EMA/EMA_Datasets.htm POC: Ed Farley, Lisa Eisner, Jim Murphy
Fish habitat & Marine Chemistry	Beach seining near Barrow AK	http://www.afsc.noaa.gov/ABL/Habitat/ablhab_datasets.htm POC: Scott Johnson, John Thedinga, Mandy Lindeberg
Marine Fish Survey, West Beaufort (2008)	Bottom trawl & acoustics	http://www.afsc.noaa.gov/REFM/stocks/fit/Beaufort.php POC: Libby Logerwell, Kim Rand
Arctic EIS: surface & bottom trawls	ArcEIS	POC: Franz Mueter, Bob Lauth, Mike Sigler
Marine Mammals: 30y+aerial surveys	ASAMM	http://www.afsc.noaa.gov/NMML/software/bwasp-comida.php [1979-2010 data] POC: Libby Logerwell, Kim Rand http://www.afsc.noaa.gov/NMML/cetacean/bwasp/index.php
Bowhead Feeding Study 2007-11; also see NSF/SNACS	BOWFEST	http://www.afsc.noaa.gov/NMML/cetacean/bwasp/index.php [annual reports]; also see NSF final reports SNACS POC: Kim Shelden
Chukchi Acoustics, Oceanographic & Zooplankton Study	CHAOZ	http://www.afsc.noaa.gov/NMML/cetacean/bwasp/index.php [annual reports] POC: Catherine Berchok, Phyllis Stabeno, Jeff Napp
Chukchi Sea Environmental Studies Program	CSESP	http://www.chukchiscience.com/StudytheScience/tabid/215/Default.aspx; funded by industry (Shell, ConocoPhillips, and Statoil)

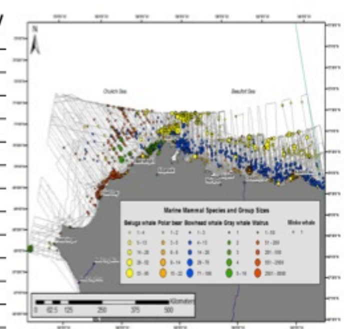
Aerial Surveys of Arctic Marine Mammals



Marine Mammal Species

	Hot Spot Analysis			
	Single Species	Cetaceans	Pinnipeds	Species Diversity & Richness
beluga	x	x		x
bowhead whale	x	x		x
fin whale		x		x
gray whale	x	x		x
harbor porpoise		x		x
humpback whale	x*	x		x
minke whale	x*	x		x
killer whale		x		x
small unid cetacean		x		
unid cetacean		x		
bearded seal			x	
ringed seal			x	
small unid pinniped			x	
spotted seal			x	
unid pinniped			x	
polar bear	x			x
walrus	x		x	x

*If sample sizes allow



Fall 2008-2011 Marine Mammal Sightings

BOEM
Bureau of Ocean Energy Management

Figure C5.12 Areal survey of Marine Mammals in the Chukchi and Beaufort Sea (Kathy Kuletz-USFWS, Megan Ferguson-NOAA, Brendan Hurley-Ecological GIS, and Elizabeth Labunski-USFWS (Presented at the PacMARS-SOAR Open Science meeting, Jan. 2013, Anchorage).

C5.6 Higher trophic level hotspots

Comparably large concentrations of bivalves (> 1000 m^{-2}; ~1 kg wet weight m^{-2}), amphipods (> 1000 m^{-2}; >25.0 g wet weight m^{-2}), and polychaetes (> 4500 m^{-2}; >100 g wet weight m^{-2}) have been documented west of and within Barrow Canyon (Grebmeier et al. 2006a, 2012, Schonberg et al. 2014). Distributions of these primary prey items for gray whales (amphipods) and walruses (bivalves, gastropods and polychaetes) were compared with gray whale and walrus population observations collected during the aerial survey component of COMIDA from July through October 2009 and 2010. For example, prime concentrations of walrus prey and feeding walruses were often observed to the south of Hanna Shoal as well as on the shoal itself in 2009 and 2010 (Fig. C5.13).

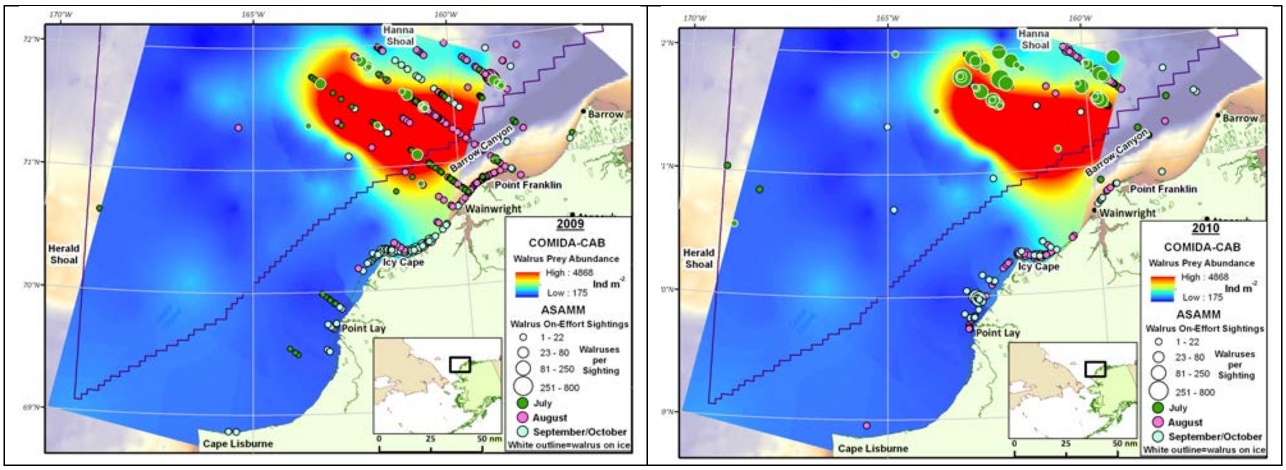


Figure C5.13 Transect sightings of walrus from July through mid-October 2009 and 2010, superimposed over interpolated (kriged) bivalve, gastropod, and polychaete (prey) abundance collected in August 2009 (left panel) and 2010 (right panel). Walrus data are from the National Marine Mammal Laboratory, National Marine Fisheries Service (http://www.afsc.noaa.gov/nmml/software/bwasp-comida.php). Benthic data are from Schonberg et al. (2014).

For Pacific walrus (*Odobenus rosmarus divergens*), these observations reveal that this species is facing a rapidly changing sea ice regime with ongoing seasonal sea ice retreat over shallow shelves in the Pacific Arctic. As sea ice retreats off the continental shelf, use of sea ice as a resting platform during feeding and rest becomes limited and changes in foraging patterns can be expected. Satellite telemetry of walruses has proven useful in evaluating short-term changes in sea ice locations, and walrus foraging relative to benthic food resources. Recent studies have been evaluating how shifts in walrus resting areas may affect their access to prey concentrations and foraging patterns (Jay et al. 2012). Understanding relationships between the distributions of dominant walrus prey and spatial patterns of walrus foraging will improve our ability to forecast how walruses might respond to a changing climate and continued seasonal sea ice retreat. . The spatial foraging choices of walruses tagged during the summer 2008-2011 reveals these important migratory patterns (Fig. C5.14, top panel). These distribution patterns can also be matched with independently collected benthic biomass and abundance data collected in the northeast Chukchi Sea (Fig. C5.14, bottom panel).

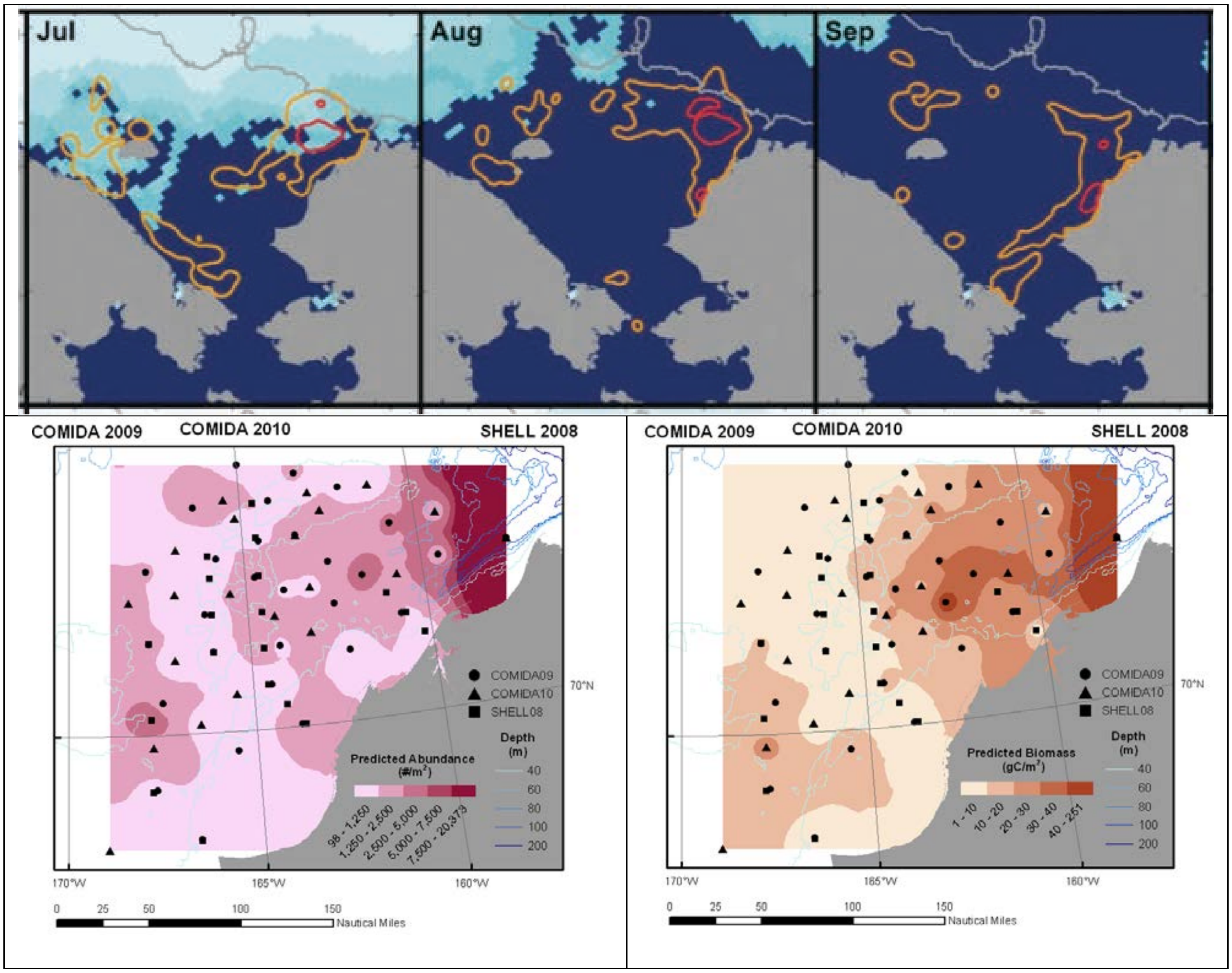


Figure C5.14. Top panel**.** Distribution of tagged walruses during July-September 2008-2011 (Jay et al. 2012). Bottom panel. Distribution of benthic macroinfaunal station abundance (left panel) and biomass (right panel) for data collected in 2008-2010 during SHELL08, COMIDA09 and COMIDA10 (modified from Grebmeier 2012 and Grebmeier unpubl. data).

Another upper level trophic species that is apparently expanding range as ice retreats are gray whales, which may be taking advantage of other areas within Barrow Canyon and the shelf west of the canyon where high concentrations of benthic amphipods have been documented (e.g. Fig. C5.15).

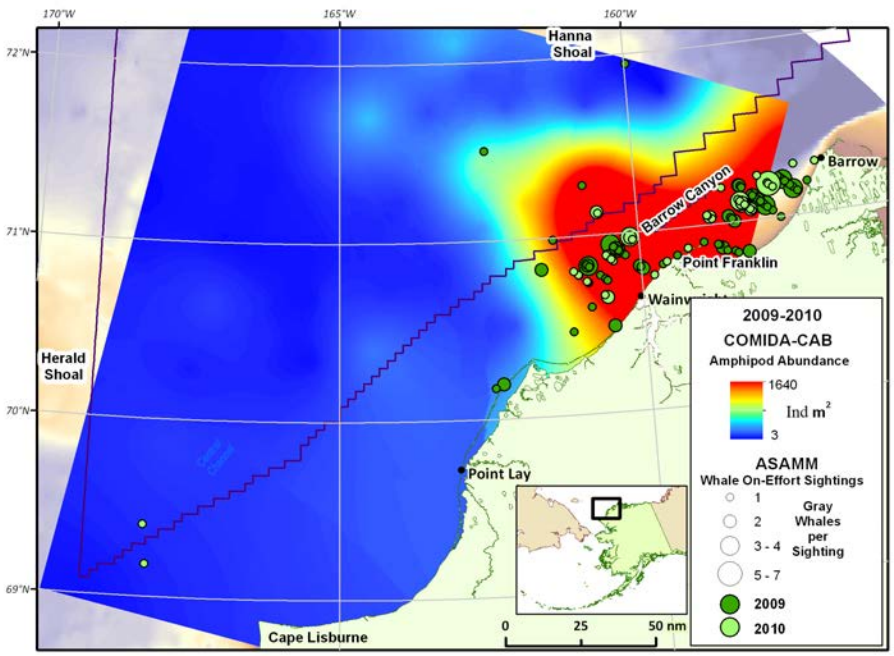


Figure C5.15 Gray whale sightings on transect during July through mid-October 2009 and 2010, superimposed over interpolated (kriged) benthic amphipod (prey) abundance data collected in August 2009 and 2010. Kriged amphipod abundance does not extend beyond known station data, especially in the deeper extensions of Barrow Canyon where gray whale sightings may indicate the presence of abundant amphipods. Gray whale data available from the National Marine Mammal Laboratory, National Marine Fisheries Service (http://www.afsc.noaa.gov/nmml/software/bwasp-comida.php). See Schonberg et al. (2014) for additional details.

C5.7 Demersal fishes

Almost 60 species of fish have been recorded from the Chukchi Sea shelf between 1959 and 2008 representing at least 13 families (Fig. C5.16, Norcross et al. 2013a). In the 15 cruises conducted from 1959 to 2008, 15 demersal fish species contributed 99% of the entire fish catch. Across the entire period, the dominant families were cods, sculpins, pricklebacks, flatfishes and eelpouts. The dominant fish taxa caught were Arctic cod (*Boreogadu saida*), Arctic staghorn sculpin, (*Gymnocanthus tricuspis*), shorthorn sculpin (*Myoxocephalus scorpius*), eelpouts (*Lycodes* spp.), Bering flounder (*Hippoglossoides robustus*) and saffron cod (*Eleginus gracilis*). These taxa were the same in historic and recent cruises. Small-mesh trawls tended to collect more species than large-mesh trawls. Generally, the most abundant fishes have a circumpolar distribution (Mecklenburg et al. 2011).

Taxon richness in the combined demersal data set showed peaks north of Bering Strait, in Kotzebue Sound and around Point Hope and Cape Lisburne (Fig. 15.7). The number and distribution of fish assemblages in the Chukchi Sea varied depending on the spatial scale and data set(s) analyzed (Barber et al. 1997, Norcross et al. 2010, 2013a,b). Fish assemblages were primarily structured by bottom temperature, bottom salinity, water mass, water depth and sediment type with different variable rankings between various cruises and not every variable influential in every cruise (Barber et al. 1997, Norcross et al. 2010, 2013a,b).

On the Beaufort Sea shelf, 43 species from 12 families have been recorded during two cruises (Rand and Logerwell 2011, Norcross et al. 2013c). As on the Chukchi shelf, dominant taxa on the shelf included

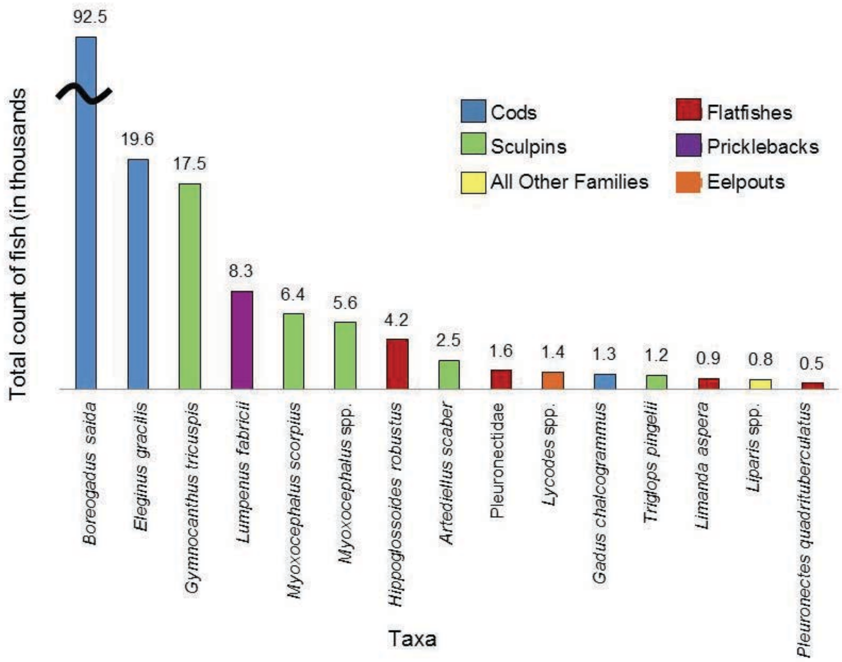


Figure 5.16. The most abundant fish taxa in the eastern Chukchi Sea between 1959 and 2008 (from Norcross et al. 2013a).

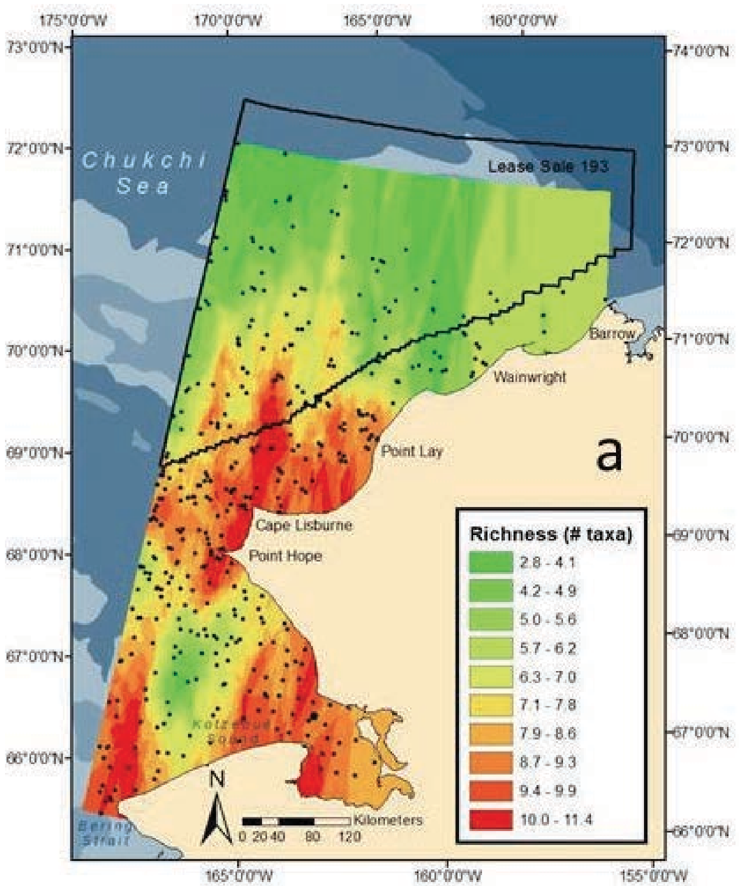


Figure C5.17 Species richness of demersal fish in the eastern Chukchi Sea from hauls taken between 1959-2008 (from Norcross et al. 2013a).

Arctic cod (by far the most dominant species), sculpins, and snailfishes (Norcross et al. 2013d), and in the western part also Bering Flounder and Walleye Pollock (Rand and Logerwell 2011). On the slope, the relative composition was dominated by eelpouts. Rays and flatfishes were present on the slope while sculpins and poachers were rare (Norcross et al. 2013d). Higher densities of fishes were found on the western than in the eastern Beaufort Sea shelf (Norcross et al. 2013d). The distribution of the dominant Arctic cod was associated with water mass structure and associated productivity levels (Logerwell et al. 2011, Crawford et al. 2012). Large schools were found associated with Atlantic water along the slopes (250-350) of the Chukchi and Beaufort Seas.

Generally, the biomass of fish was overwhelmingly lower than that of epifaunal invertebrates in the Chukchi and Beaufort Seas (Rand and Logerwell 2011, Bluhm, Norcross et al. unpublished data). By contrast, the contribution of fish to total benthic biomass is much larger in sub-Arctic seas such as the eastern Bering Sea and the Barents Sea (Stevenson and Lauth 2012, Hunt et al. 2013).

C6. Chemical Contaminants in Sediments and Biota

C6.1 Contaminants in sediments

The following contaminants are included in the PacMARS data base for sediments: (1) metals including Ag, Al, As, Ba, Be, Cd, Co, Cr, Cu, Fe, total Hg, Methyl Hg, Mn, Pb, Sb, Se, Sn, Tl, V and Zn, (2) petroleum hydrocarbons with n-alkanes (including pristine and phytane), total petroleum hydrocarbons and saturated hydrocarbons and (3) PAH including ≥42 parent compounds plus eight alkyl isomers. Very few data are available for chlorinated hydrocarbons, including pesticides in marine sediments. Concentrations of sediment metals and PAH vary widely throughout the PacMARS study area in response to variations in sediment grain size, total organic carbon (TOC) concentrations and mineralogy as described below. The representative data in Table C6.1 show both the large standard deviations and ranges for potential contaminants in sediments from the Chukchi and Beaufort seas. Maximum concentrations of Cd, total Hg, Pb, and TPAH are all above background values (Table C6.1). However, the fraction of samples with concentrations that exceed background values are few in number and discussed below. A few summary data are included here so that the reader can put concentrations in perspective with studies from other locations globally. Median concentrations of Cd, total Hg, Pb, and TPAH in Table C6.1 are representative of background values as described below. Mean concentrations of TPAH are 20-30% higher than median concentrations because a few very high values have been recorded for sediments containing drilling mud and cuttings.

Table C6.1 Summary data for selected metals and organic substances in surface sediments from the Beaufort and Chukchi seas.

	Al (%)	TOC (%)	Silt + Clay (%)	Cd (µg/g)	ΣHg (µg/g)	Pb (µg/g)	TPAH (ng/g)
Beaufort Sea (n = 368-452 samples as a function of availability in various data bases)							
Mean ± SD	4.34 ±1.63	1.07 ±0.95	50 ±23	0.20 ±0.09	0.043 ±0.025	11.9 ±5.2	620 ±906
Median	4.46	0.79	54	0.19	0.043	12.0	506
Maximum	8.88	7.36	99	0.75	0.270[1]	50.4	4,060[1]
Minimum	1.03	0.02	0.1	0.03	0.003	2.8	9
Chukchi Sea (n = 206-218 samples as a function of availability in various data bases)							
Mean ± SD	5.30 ±1.07	0.88 ±0.33	43 ±23	0.17 ±0.04	0.034 ±0.015	11.5 ±2.0	532 ±906
Median	5.52	0.85	44	0.17	0.033	11.5	400
Maximum	7.80	1.79	95	0.38	0.190	21.5	11,000
Minimum	1.03	0.03	2	0.04	0.005	5.4	5

[1]Contains natural sulfide (Hg) or perylene (TPAH).

The distribution of metals and PAH in arctic sediments parallels trends for silt + clay and TOC with a patchy distribution as shown for the Chukchi Sea in Fig. C6.1. For example, concentrations of total mercury (THg) and TPAH in the northeastern Chukchi Sea are low in coarse-grained, TOC-poor sediments nearshore and on Hanna Shoal and higher in fine-grained, TOC-rich sediments (Fig. C6.1).

Metals and organic substances (including TOC) are adsorbed to the greater surface area clay minerals rather than to coarse-grained sands. The contours show patterns that are independent of any sediment contamination because the distribution of metals and PAH vary naturally as a function of grain size and TOC. Contour maps for the Beaufort Sea and other PacMARS locations show the same patchy distribution. Therefore, identification of background concentrations and subsequently sediment contamination requires normalization of concentrations as described below. As discussed previously for other themes in this synthesis, sediment grain size also plays an important role in species composition and abundance.

Sediment metal concentrations were normalized to Al (a proxy for silt + clay and TOC) to identify background values. This approach is discussed in detail in Trefry et al. (2003, 2013, 2014). Using the

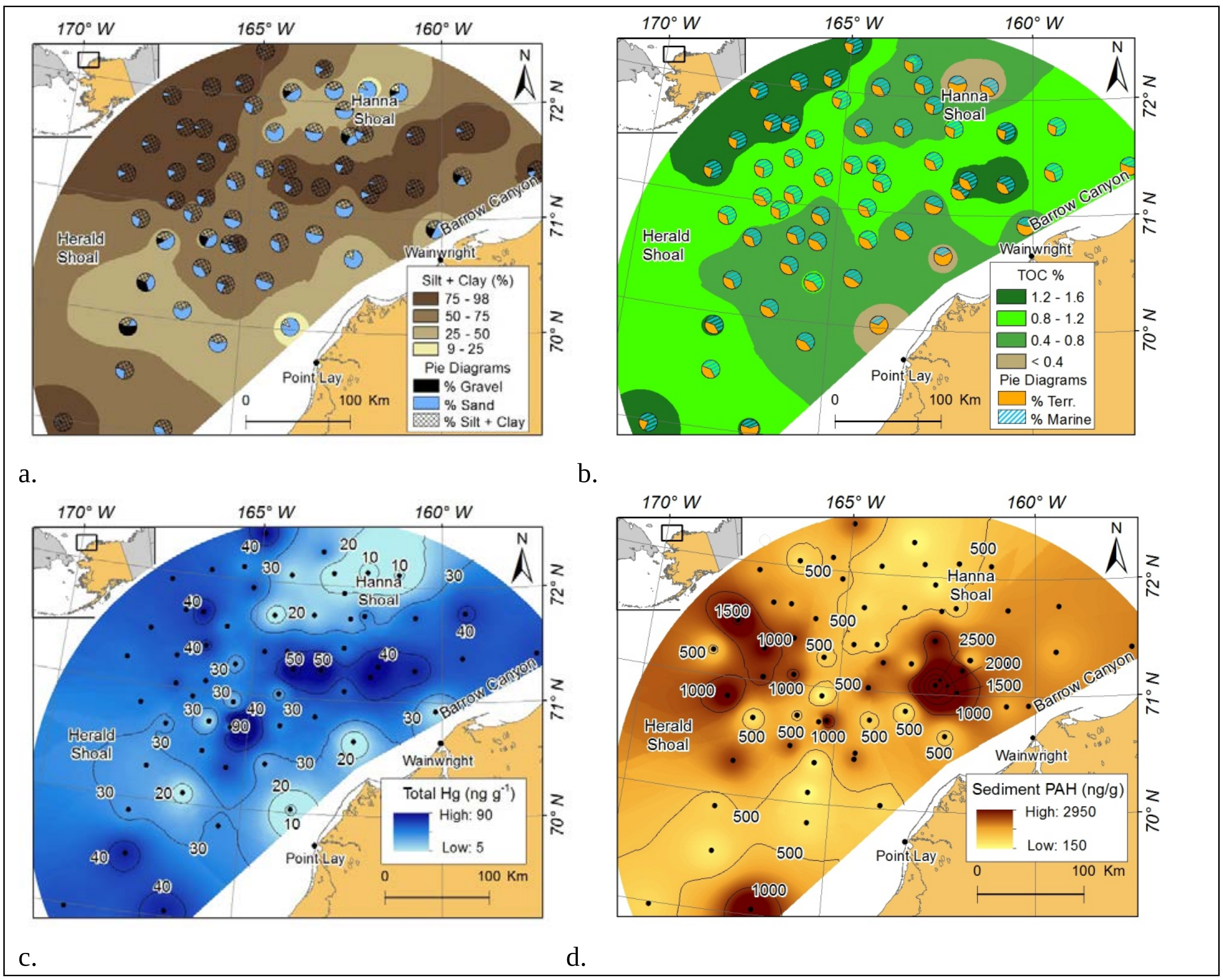


Figure C6.1 Contour maps for surface sediment (a) grain size, (b) total organic carbon (TOC) and % terrestrial and marine OC based on data for $\delta^{13}C$, (c) total mercury and (d) total polycyclic aromatic hydrocarbons (TPAH) in the northeastern Chukchi Sea.

PacMARS data set, metal versus Al plots are shown for total Hg, Pb and Cr for the Beaufort and Chukchi seas (Fig. C6.2). The linear regression lines and 99% prediction intervals were constructed using baseline data from the ANIMIDA (Trefry et al. 2003) and COMIDA (Trefry et al. 2014) projects for the Beaufort and Chukchi seas, respectively. All data points from the complete PacMARS data base were then added to each graph (Fig. C6.2).

Three data points (0.7% of 407 total data points) for total Hg in the Beaufort Sea plotted above the upper prediction interval and therefore are considered to be above background, possibly due to the presence of contaminant Hg (Fig. C6.2). The anomalous Hg values for stations 5D and N14 near Prudhoe Bay were shown convincingly by Brown et al. (2010) to be due to the presence of trace amount of a naturally occurring Fe sulfide. The anomalous Hg value from station BL03-5 in Beaufort Lagoon may be due to minor Hg contamination or to a metal sulfide. For Pb, 3 of 468 data points (0.6% of the Pb values) plotted above background, two were associated with drilling mud and cuttings in Camden Bay (Trefry et al. 2013) and one was associated with the trace sulfide mineral collected at station N14 (Brown et al. 2010).

A summary of results for other metals in the coastal Beaufort Sea (Table C6.2) shows that a relatively small fraction of the samples are contaminated. The overall trend for the Chukchi Sea was similar with

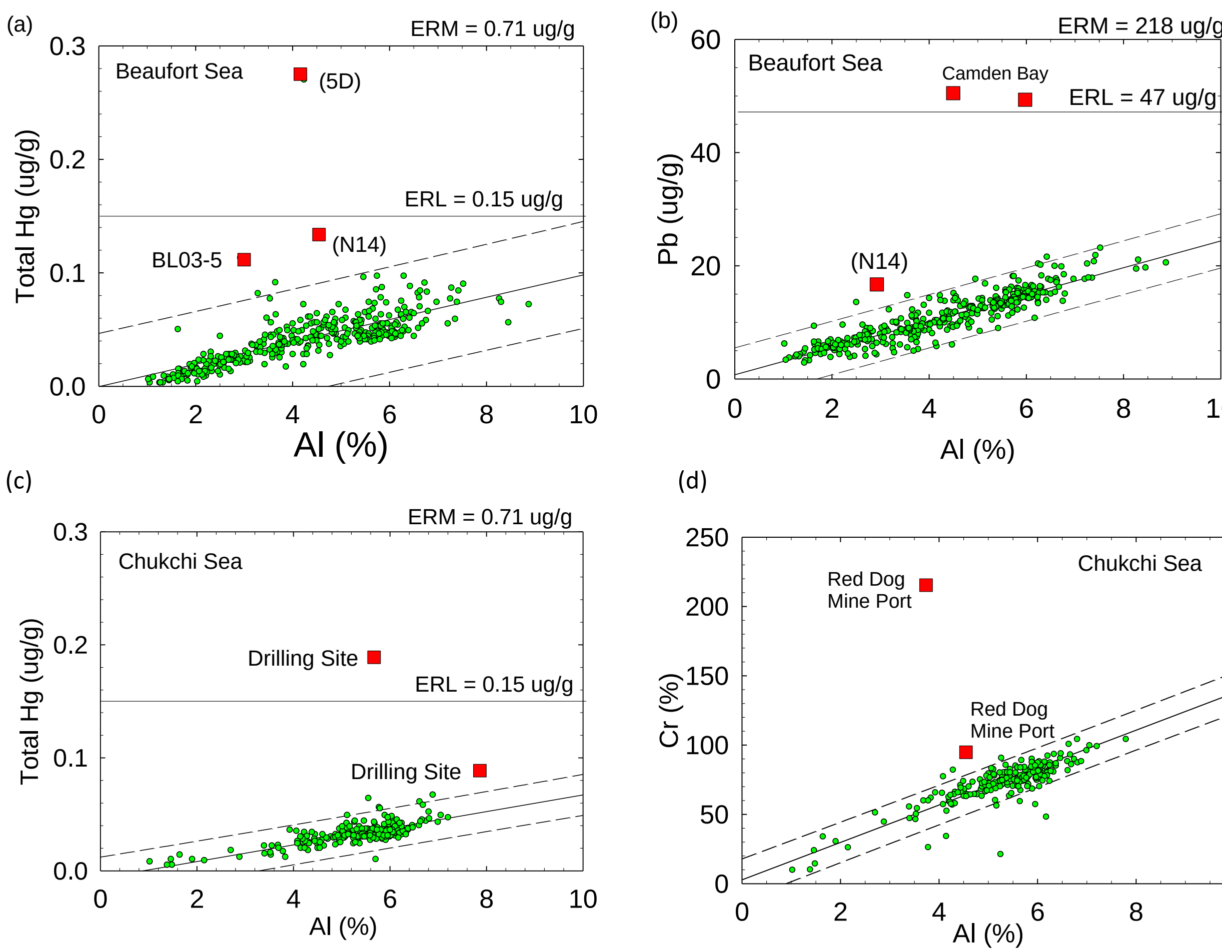


Figure C6.2 Concentrations of: a. total mercury and b. lead in surface sediments from the Beaufort Sea and c. total mercury and d. chromium in surface sediments from the Chukchi Sea using the complete PacMARS data set. Solid lines are from linear regressions and dashed lines are prediction intervals based on previously established background data from each sea.

very few sites showing metal contamination (Table C6.2). One example plot for total Hg in surface sediments from the Chukchi Sea shows two Hg hotspots near old drilling sites; the second example plot shows high Cr values near the port for the Red Dog Mine (Fig. C6.2).

In contrast with Hg in biota, where methylmercury (MeHg) is the dominant form of Hg, <1% of the total Hg in sediments is typically present as MeHg. For example, Fox et al. (2014) determined that only 0.43 ± 0.17% of the sediment THg in the northwestern Chukchi Sea was present as MeHg. Such low values for MeHg are common for marine sediments. The percent of THg that was MeHg in Beaufort Sea sediments averaged 0.7 ± 0.4% with 22 of 30 samples having <1% of the THg present as MeHg (Brown et al., 2004). If the sediment redox environment in the Arctic changes in the future due to increased deposition and decomposition of organic matter, the fraction of MeHg in the sediments may increase, possibly to >1%.

Sediment PAH contamination was been determined by plotting (1) TPAH versus silt + clay and (2) ln (TPAH – perylene) versus ln (perylene + 1) (Brown et al. 2004). In the first method, natural concentrations of PAH, like metals, are higher in fine-grained sediments due to the higher surface area for adsorption; anomalously high PAH values relative to % silt + clay are often due to a contaminant

Table C6.2 Numbers of data points that exceeded the upper prediction interval (UPI) or effects range-low (ERL) showing possible pollution for metals. Total numbers of data points for the Beaufort and Chukchi seas were 407-477 and 105-233, respectively.

# Data Points	Beaufort Sea (>UPI)	Beaufort Sea (>ERL)	Chukchi Sea (>UPI)	Chukchi Sea (>ERL)
0	Be, Ni, Sb, Tl	Ag, Cd, Cu, Hg, Ni, Zn, TPAH and individual PAH	Ag, Be, Co, Sb, Tl, V, Zn	Ag, Cd, Cu, Pb, Zn, TPAH and individual PAH
1-3	Ag, Co, Hg, Pb	Pb	Cd, Cr, Hg	Hg, TPAH
4-6	V, Zn	None	Pb	None
6-10	Cr,	None	None	None

ERLs from Long et al. (1995) and O'Connor (2004). Metal in values in µg/g: Ag (1.0), Cd (1.2), Pb (47), Hg (0.15), Zn (150). Organic substance values in ng/g: TPAH (4000), Anthracene (85), Benzo-a-pyrene (430), ΣDDT (1.6), ΣPCBs (23).

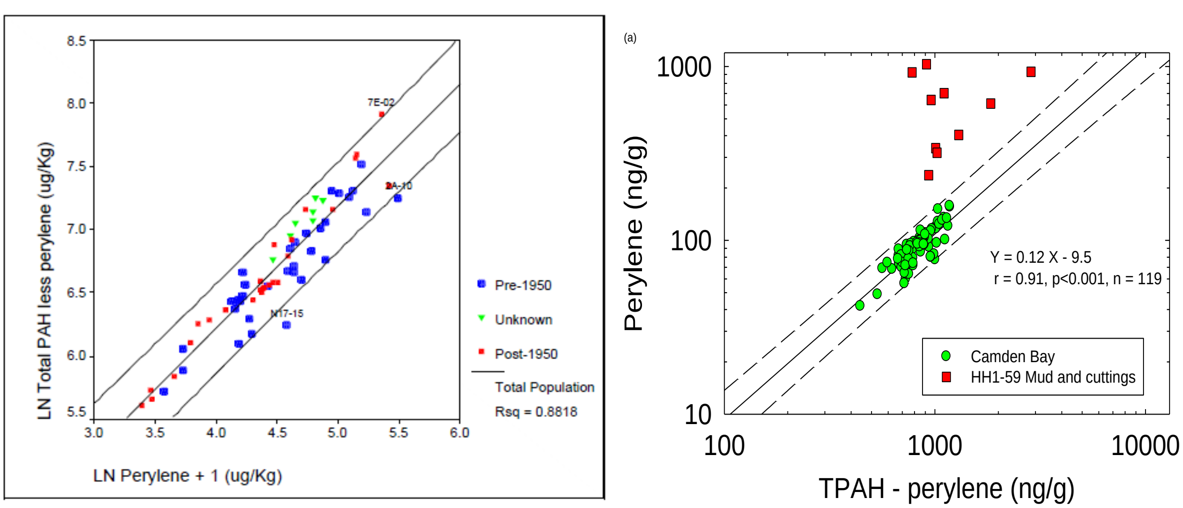


Figure C6.3 (a) Ln total polycyclic aromatic hydrocarbons (TPAH) less perylene versus ln perylene +1 and (b) perylene versus TPAH – perylene.

source. In the second method, background concentrations of PAH were shown to vary with perylene content. Perylene is a naturally occurring PAH that is formed during long-term diagenesis of organic matter (Venkatesan 1988). Thus, data for samples enriched in PAH plot above the upper prediction interval on a plot of ln (TPAH – perylene) versus ln (perylene + 1) (Fig. C6.3, Brown et al. 2010). Fig. C6.3 shows that essentially all sediment data from the Beaufort Sea, excluding Camden Bay drilling sites, plot within the 95% prediction interval, indicating natural, background concentrations (Brown et al., 2010). In deposits from Camden Bay that contained drilling mud and cuttings, concentrations of perylene were enhanced, most likely due to organic-rich cuttings that were drilled from the ancient sedimentary formation (Trefry et al., 2013).

Sediment cores provide an historical record of metal and PAH contamination and have been described in Trefry et al. (2003, 2013, 2014), Brown et al. (2004, 2010), Neff et al. (2009), Belicka et al. (2009), Fox et al. (2014) and Harvey et al. (2014). The results show centuries of no discernible changes in concentrations of potential contaminants, including Hg, Pb and PAH, except in the immediate area (<200 m) of the five drilling sites (of 30 total in the Alaskan Arctic) studied to date. Concentrations and sources of PAH in the coastal Beaufort Sea have been generally uniform for the past 50-100 years with no statistically significant increases (after normalization) in hydrocarbon concentrations in the Prudhoe Bay area since oil and gas development began in the 1970s (Brown et al. 2010). Vertical profiles and details are available in the references listed above.

Possible pollution due to elevated concentrations of metals and TPAH in sediments was assessed using the sediment quality criteria of Long et al. (1995) where the effects range low (ERL) and effects range median (ERM) are the 10^{th} and 50^{th} percentile values from an ordered list of concentrations of substances in sediments that are linked to a biological effect. Several authors have noted that the sediment quality guidelines should be used cautiously with an appropriate understanding of their limitations (Field et al. 2002, O'Connor 2004). For example, O'Connor (2004) stated that the ERL is a concentration at the low end of a continuum that relates chemistry with toxicity and that the utility of the sediment quality criteria is to call attention to a specific site where additional study, such as determining benthic biomass and community structure, may be warranted. The application of ERLs and ERMs to the sediment data from the PacMARS synthesis are presented here with these caveats. In addition, there are difficulties with ERL values for As, Cr and Cu because the ERL concentrations are lower than concentrations in typical continental crust (O'Connor, 2004). Sediment quality guidelines are available for nine metals, TPAH, 14 individual PAH, total DDT and total PCBs.

No concentrations of any chemical in sediments from the PacMARS study area exceed the ERM. Furthermore, concentrations of all metals except Pb at two stations in the Beaufort Sea and Hg one station in the Chukchi Sea did not exceed the ERL (Table C6.2). Concentrations of TPAH exceeded the ERL at one station in the Chukchi Sea. The key point from the synthesis is that sediment metal and PAH contamination is very limited and the sediments are essentially pristine. In addition to concentrations of total PAH, the assemblage of various PAH compounds in sediments can be used to identify possible sources, In the Beaufort and Chukchi seas, the PAH assemblage in most sediment samples shows a full suite of parent and alkyl PAH (Fig. C6.4-left panel). This distribution is typical for a mixture of sources including pyrogenic (from pyrolysis and combustion of organic matter), petrogenic (from fossil fuels), and biogenic (from recent anaerobic diagenesis of certain natural organic chemicals). The PAH assemblage shown in Fig. C6.4a at average TPAH concentrations of ~600 ng/g is typical background for the region. In contrast, the PAH distributions in sediments from an historic drill site at Klondike (station KD005) in the Chukchi Sea differ because they are enriched in parent and alkylated naphthlenes (Figure C6.4-right panel), a distribution typical for Alaskan crude oil. Overall, the distribution of PAH in the PacMARS area is consistent with background concentrations and PAH assemblages.

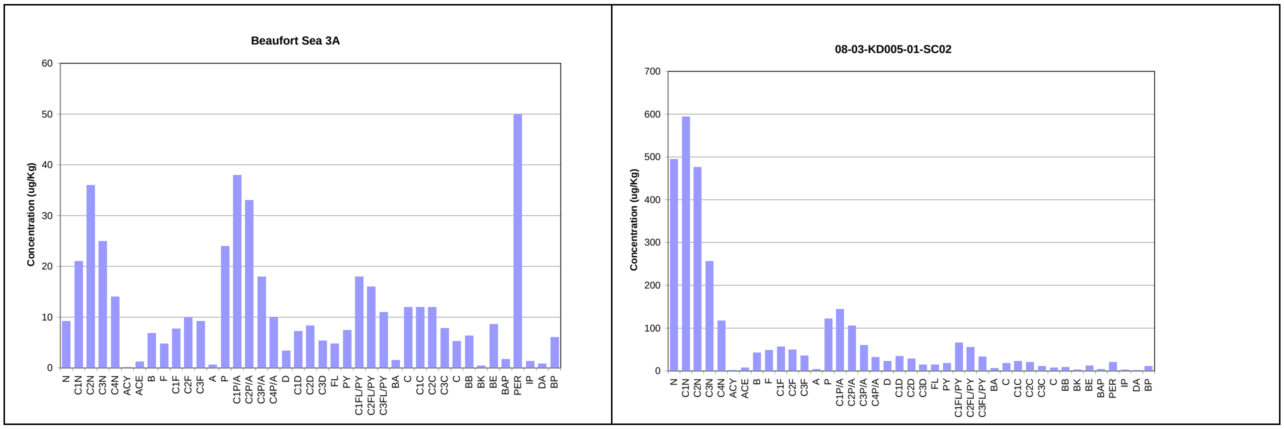


Figure C6.4 Distribution of individual PAH compounds in (left panel) a typical sediment from the Beaufort or Chukchi seas where TPAH averages about 600 ng/g and (right panel) in sediments around the Klondike drilling site where TPAH was 3100 ng/g. (after Neff et al., 2009; compound abbreviations in G6).

C6.2 Contaminants in benthic biota

Data for contaminants in benthic infauna/epifauna from the Beaufort Sea (n = 156; including amphipods and clams) and Chukchi Sea (n = 149; including amphipods, clams, whelks, crabs) have been added to the PacMARS database. Samples from the Beaufort and Chukchi seas were collected from 1984-2008 and 2009-2010), respectively. Contaminant data for fish have been added to the PacMARS database with 25 samples from the Chukchi Sea and 88 samples from the Beaufort Sea. Concentrations of contaminants in benthic biota and fish in the PacMARS data base are tabulated on a dry weight basis; however, water content data are available to enable users to calculate wet weight concentrations.

Time series data with good QA/QC are available through various sources for metals and PAH in samples of amphipods (*Anonyx* spp.) and clams (*Astarte* spp.) from the coastal Beaufort Sea for 1986-2006 (Boehm et al., 1990; Brown et al., 2004, 2010; Neff et al., 2009; Neff and Durell, 2012). Samples were collected from Camden Bay to Harrison Bay (143-154° W) as part of the ANIMIDA and cANIMIDA projects (Figure B6.2). Average concentrations of metals that are well regulated by these organisms (e.g., Cu, Zn) had relative standard deviations (RSDs) of 18-25% for each of the complete data sets of 54 amphipod and 22 clams (Figures C6.5 and C6.6 for Zn).

The other metals, TPAH and individual PAH have RSD values that range from 25-60% (Figures C6.5-C6.7). Identifying statistically significant changes in concentrations of contaminants in these organisms depends upon (1) a relatively low RSD and (2) low analytical detection limits. Concentrations of total Hg and Pb in amphipods show slight trends of increasing and decreasing, respectively, over time. No clear trends were found for total Hg and Cd in clams. It is clear that identifying contamination and temporal trends with invertebrate data is difficult and it is reasonable to conclude that there is no evidence of metal or PAH contamination in the amphipods or clams analyzed.

One interesting spatial trend observed for Hg in snow crabs (*Chionoecetes opilio)* and whelks (*Neptunea heros)* in the Chukchi Sea was linked to benthic biomass and perhaps shows the complexity of establishing background concentrations of contaminants. For example, the lowest concentration of THg (46 ng/g) in *C. opilio*, was found near the head of Barrow Canyon where total benthic biomass was 561 g/m^2. In contrast, the highest concentration of THg for *C. opilio* (288 ng/g) was obtained at a station where the total benthic biomass was 103 g/m^2 (Fig. C6.8). Although this trend was not well defined, values for THg in *C. opilio* from stations with a total benthic biomass >400 g/m^2 were <100 ng/g and only

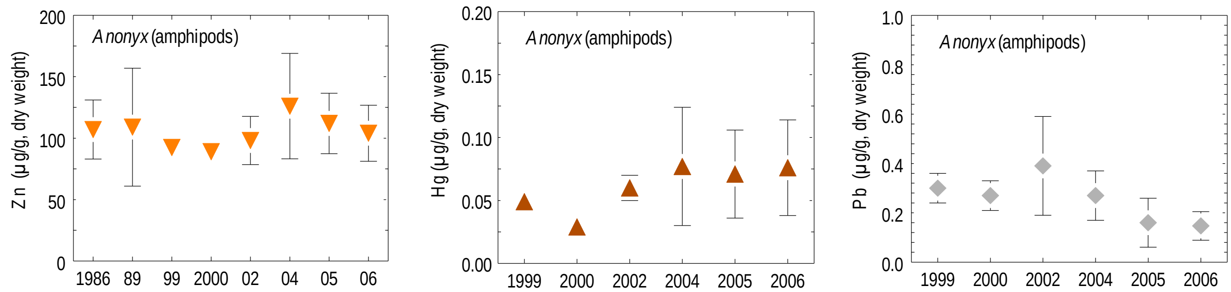


Figure C6.5 Concentrations of zinc, total mercury and lead in amphipods (*Anonyx* spp.) from the coastal Beaufort Sea. Markers show the annual mean concentrations and lines show ±1 standard deviation (SD). Markers with no lines have an SD that is smaller than the marker.

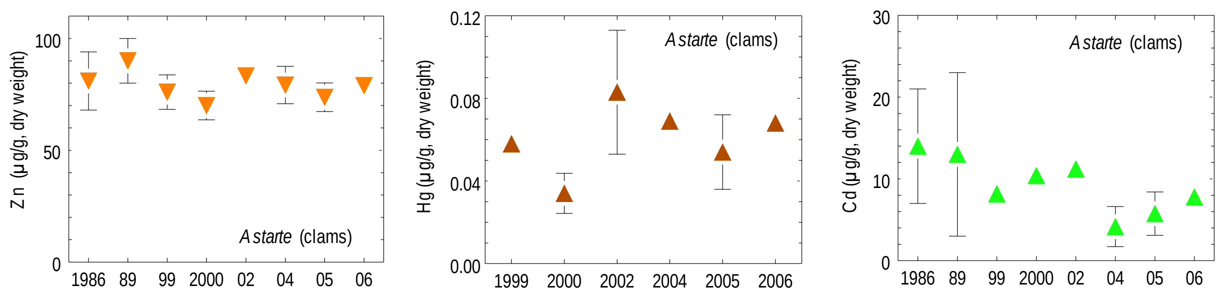


Figure C6.6 Concentrations of zinc, total mercury and cadmium in clams (*Astarte* spp.) from the coastal Beaufort Sea. Markers show the annual mean concentrations and lines show ±1 standard deviation (SD). Markers with no lines have an SD that is smaller than the marker.

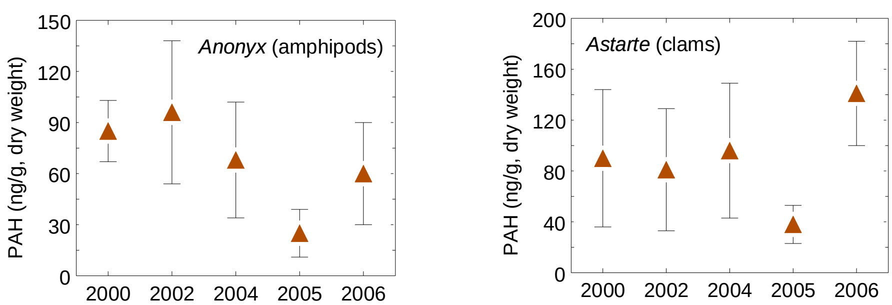


Figure C6.7 Concentrations of total polycyclic aromatic hydrocarbons amphipods (*Anonyx* spp) and clams (*Astarte* spp.) from the coastal Beaufort Sea. Markers show the annual mean concentrations and lines show ±1 standard deviation (SD).

samples collected from sites with total benthic biomass <300 g/m^2 contained THg at >100 ng/g (Fig. C6.8). This trend is consistent with results from previous investigations in pelagic systems that have shown decreased concentrations of Hg in plankton during algal blooms due to a limited supply of dissolved THg and a large algal biomass (see Fox et al. 2014). Lower concentrations of Hg at the base of the food web in highly productive areas would likely lead to decreased Hg content in higher trophic levels organisms.

Biomagnification in the benthic food web in the northeastern Chukchi Sea was identified by a significant positive relationship for MeHg versus values for δ^{15}N (Figure C6.8). The slope of this regression (0.19)between concentrations of MeHg and δ^{15}N has been commonly referred to as the biomagnification

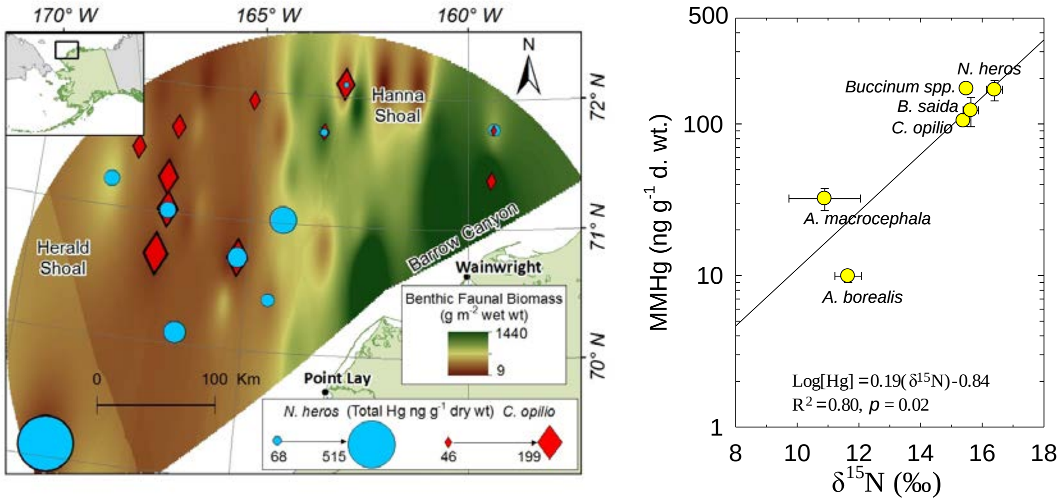


Figure C6.8 (a) Contour map for benthic biomass, with markers showing concentrations of total Hg (THg) in *N. heros* and *C. opilio* and (b) concentrations of methylmercury (MeHg) versus δ^{15}N. Solid line and equation from linear regression calculations, R^2 is the coefficient of determination and *p* is the statistical *p*-value.

power (e.g., Atwell et al., 1998). Using a biomagnification power of 0.19 and δ^{15}N values for each organism shown in Fig. C6.8, MeHg concentrations were 11 times higher in *N. heros*, (the highest trophic level) than in *A. macrocephala* (an amphipod at the lowest trophic level). The biomagnification power for the benthic food web in the NECS (0.19) was lower than the value of 0.20 reported by Lavoie et al. (2010) for benthic organisms and sea birds in the Gulf of St. Lawrence, Canada. Biomagnification is considered in more detail in the Section C7.2 on contaminants in upper trophic level organisms.

C6.3 Contaminants in marine mammals and seabirds

Extensive efforts to determine and understand the enrichment of selected chemicals in marine mammals and birds in the Arctic have been ongoing for more than two decades (e.g., AMAP 1997, 2011). Chemicals such as mercury and organochlorine compounds (e.g., PCBs) are noteworthy because they are transported from outside the Arctic via the atmosphere and condense in the cold arctic air where they are biomagnified to high concentrations in upper trophic level organisms such as beluga, ringed seal, polar bear and birds of prey. In the case of Hg, for example, concentrations are reported to have increased ten-fold in these animals over the past 150 years with ~90% of the present-day body burden of Hg believed to be anthropogenically derived (AMAP 2011). Recent time-series data for Hg (past two decades) show significantly increasing trends for marine species, followed by freshwater fish species with no significant increases in Hg in terrestrial animals (AMAP 2011).

Syntheses for contaminants in higher trophic level organisms have been carried out very well (e.g., AMAP 2011) and will not be repeated during PacMARS. Rather, our synthesis paper focuses on linking contaminant data for sediments and benthic biota (the beginning of the biomagnfication process) with data for higher trophic level organisms. Investigation of this linkage is valuable in light of (1) reported trends of increasing contamination in marine species and (2) differences found for Hg concentrations in benthic biota as a function of benthic biomass (Fig. C6.8). The data set for contaminants in upper trophic level biota for the PacMARS study area is dwarfed by very large data sets for the Canadian Arctic, Greenland and Svalbard. Nevertheless, we are optimistic that the data available for the synthesis paper in the PacMARS data base are sufficient and of high quality to meet our synthesis goal (e.g., Hoekstra et al. 2003, Dehn et al. 2005, 2006, 2007, O'Hara et al. 2006, Bentzen et al. 2008, Cardona-Marek et al. 2009).

In the Arctic, MeHg biomagnifies by >200-fold from lower trophic level organisms such as zooplankton and bivalves to higher trophic level organism such as seals and seabirds (Wagemann et al. 1998, Jaeger et al. 2009, Fig. C6.9). For example, THg concentrations in edible muscle tissue from ringed seals in the Eastern Arctic averaged 1,850 ng g^{-1} d. wt. (Wagemann et al. 1998) relative to 8 ng g^{-1} d. wt. for zooplankton from the Beaufort and Chukchi seas (Neff et al., 2009). Variability in concentrations of compounds that are biomagnified in the food web of the PacMARS study area (e.g., MeHg, PCBs) have been explained by differences in regional sources of contamination rather than trophic position (e.g., Hoekstra et al. 2003, Cardona-Marek 2009). For example, Bentzen et al. (2008) reported that the range in concentrations of organochlorine compounds in Alaska polar bears was not explained by age, sex, physical condition or reproductive status. We believe that variations in concentrations of potential contaminants in pelagic and benthic prey (partly controlled by available biomass) may contribute to observed regional differences for contaminants in upper trophic level animals.

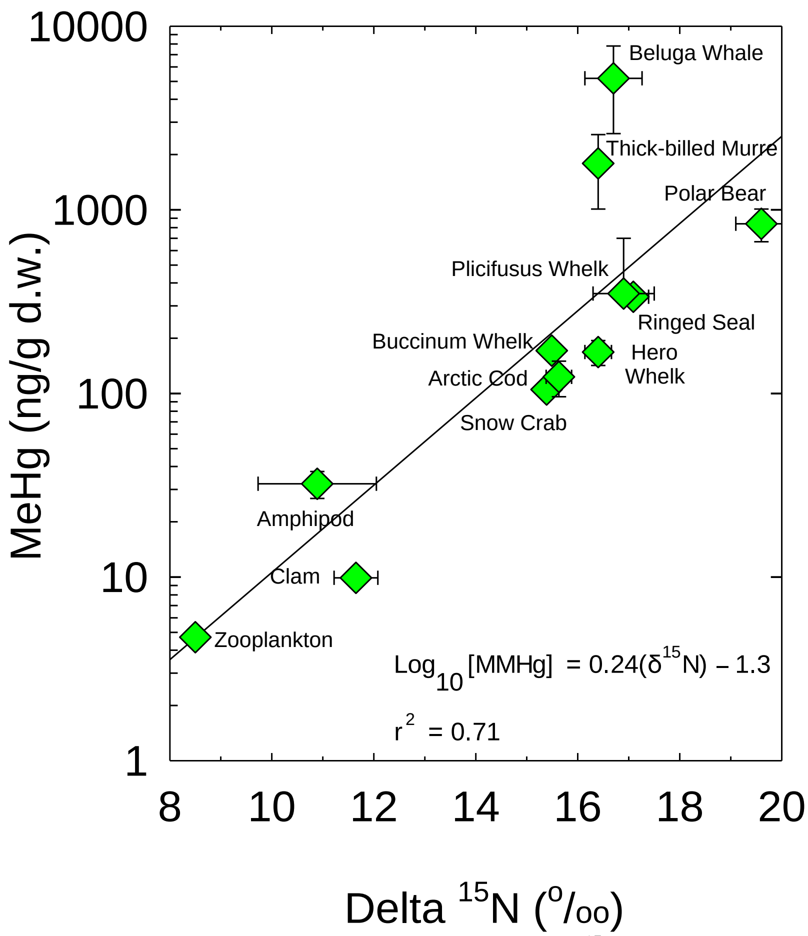


Figure C6.9 Concentrations of methylmercury (MeHg) versus δ^{15}N for marine biota from zooplankton to higher trophic level animals. Solid line and equation are from a linear regression, R^2 is the coefficient of determination.

C7. Interactions of Climate Change and the Subsistence Way of Life in the Coastal Alaskan Arctic

C7.1 Human communities of the PacMARS study region

The North Pacific Research Board defined the geographical scope for the PacMARS coverage of the human environment to include the communities of Kaktovik, Nuiqsut, Barrow, Wainwright, Point Lay, Point Hope (part of the North Slope Borough), Kotzebue, Kivalina, Buckland (part of the Northwest Arctic Borough), Brevig Mission, King Island, Shishmaref, Teller, Nome, Gambell, Savoonga, Wales, and Diomede (part of the Bering Strait region). Barrow, Kotzebue, and Nome are generally larger settlements (population 3000-5500) than other villages (population 115-700). These three communities also function as regional hubs for the North Slope, Northwest Alaska, and Bering Strait regions. A number of contemporary villages within the PacMARS study region are situated at sites of ancient settlements, such as Tigigaq (Point Hope) Utquagvik (Barrow), or Sivuqaq (Gambell). Others, such as King Island, continue to preserve a strong sense of community identity despite the history of outmigration or relocation from their historical homelands. Today's settlements in Arctic Alaska, including those situated close or near the sites of their ancestral occupation, have emerged as a result of consolidation and settlement of smaller groups, each migrating within its established subsistence territory. While the languages they spoke may have been mutually intelligible, the distinct groups asserted their unique identities through the territories they inhabited and the shared seasonal cycles of subsistence, migration, and ceremony (Burch 1998, Krupnik and Chlenov 2013).

Linguistically and in their cultural self-identification, the indigenous residents of Gambell and Savoonga are predominantly Yupiget (*singular* Yupik), whose heritage language is Saint Lawrence Island Siberian Yupik. Russia's neighboring Chukotka Peninsula is home to other Siberian Yupik language variants. In all other villages within the PacMARS study area, Inupiat (*singular* Inupiaq) are the predominant indigenous population. Variants of the Inupiaq language span the Arctic and Subarctic regions of the North America, from the central Bering Strait to the east coast of Greenland. The modern-day diffusion of Inuit languages, related to Inupiaq and Yupik, is the legacy of a grand human migration, made more extraordinary by the unique environment in which this migration occurred. For millennia, the North American Arctic has been home to people whose cultural systems and livelihoods were entwined within a coastal landscape covered with snow and ice most of the year.

The communities within the PacMARS study region share many features with other rural settlements in Alaska, many of which are home to federally recognized tribes. At the level of local governance, they are administered through a tri-partite structure consisting of municipal government, village corporation, and Native Village IRA Tribal Council. The last acts as the authoritative body on behalf of the tribe in government-to-government communications and other engagements. When state and federal agencies plan activities that will affect a federally recognized tribe, they are federally mandated to conduct government-to-government consultation with the Native Village IRA Tribal Councils. A widely accepted view is that all researchers should seek informed collaborative relationships with the people living in their region of study. The National Science Foundation *Principles for the Conduction of Research in the Arctic* state:

> All researchers working in the North have an ethical responsibility toward the people of the North, their cultures, and the environment… Cooperation is needed at all stages of research planning and implementation in projects that directly affect northern people. Cooperation will contribute to a better understanding of the potential benefits of Arctic research for northern residents and will contribute to the development of northern science through traditional knowledge and experience (https://www.nsf.gov/geo/plr/arctic/conduct.jsp, accessed 05/2014).

Other features of the communities in our study region (that are also common to the majority of modern-day rural communities in Alaska) are the absence of access to centralized road system, high cost of retail products, and a way of life that is reliant on the procurement of animals, plants, and other resources obtained through firsthand foraging, and via sharing between families and extended networks. The domain of the myriad activities, skills, areas of knowledge, and cultural values accompanying this way of life are termed by the broadly encompassing notion of subsistence.

C7.2 Coastal adaptations in Arctic Alaska

The physical locales of the human settlements within the PacMARS study region are in the coastal zones of the Beaufort, Chukchi, and northern Bering Sea. The fact that these communities are situated on the coast (or near the coast, as in the case of Nuiqsut) does not specifically distinguish their subsistence values. Sharing of resources, collaboration, and view of the subsistence way of life as a defining marker of one's identity, culture, and attachment to place are the common characteristics for both, the coastal and inland dwellers. The coastal communities do not rely exclusively on marine resources, while great many inland communities place great importance on consuming seal, walrus, whale, crab and other ocean products, which they obtain through customary sharing (Whiting et al. 2011).

The communities in our study region also have a range of experiences that are common to the coastal zones on the whole. Coasts and shorelines have been described as "liminal spaces" (Scarre 2002:2), which are boundary environments that connect elements, change physically through tidal cycles, provide habitat to creatures that combine aquatic and terrestrial adaptation, and offer a distinctive aural and visual ambiance (Helskog 1999). The elements of coastal cosmologies attribute transforming capabilities through which particular aquatic and terrestrial creatures change into one other.

Thus, the Arctic coastal communities show numerous resemblances with the inhabitants of coastal zones in the more temperate climates. They also share their resource base with Arctic communities that are not on the coast. At the same time, the human environment along the shores of the Beaufort, Chukchi, and northern Bering Sea has a number of distinctive characteristics. One that is of utmost relevance to the questions of climate change impacts is sea ice. Whereas land and water boundaries of other marine coastal zones shift with the tidal rhythms, the shorefast ice is said to extend the land around the Arctic communities during much of the year. Local knowledge delineates many interdependencies between animal behavior and ice conditions, noting preferences for specific qualities of ice among certain species. For example, Barrow hunters believe that multi-year ice provides feeding advantages for bowhead whales and attracts them with its shininess. Deep keels and ridges in the multi-year ice are attributed an ability to churn water and stir up krill (Druckenmiller 2011). Around Kotzebue Sound, when pursuing bearded seal, hunters look for clear ice, because they know that the animals do not like the areas of ice that are perceived as dirty or gray (Whiting et al 2011). Polar bears are said to prefer to follow the rough edges, rather than flat areas, when moving across pack ice (Nelson cited in Russel 2005:72).

Contrary to the marine science perspective that places sea ice within the construct of "marine environment," the indigenous geographies regard icescapes as a seasonal continuity of the human cultural landscape, populated by named places, travel routes, navigation markers, geophysical characteristics, and user memories (Aporta 2010, Druckenmiller 2011, Druckenmiller et al. 2013, Gearheard et al 2013, Kassam 2009, Nelson 1969, Oozeva et al. 2002, Weyapuk and Krupnik 2012, Wisniewski 2010a,b). Studies that have been done to date emphasize that indigenous knowledge of sea ice is highly localized, with each community possessing a unique system of meanings and practices attributed to the morphology, seasonality, human-animal interactions, safeguards, and indicators of change. Kassam (2009) asserts that "extrapolation from Wainwright, Alaska, indigenous knowledge cannot be done even to a community like Barrow, Alaska, a mere 136 kilometers to the northeast on the same coast and in the same state." (Kassam 2009:189). The coastal hunters have an elaborate system of indicators, which has been developed continuously by generations of users who implement it for safety, place finding, and pursuit of pray. Krupnik (2002) notes that of numerous Yupik terms that describe wind, each is an "information package," communicating not only the direction and intensity of the wind, but also its impact on the weather, snow, ice movement, and hunting opportunities. Such well-defined constellation of factors corresponds with the science quest for precision, albeit the precision of Yupik and Inupiaq weather terms is established through a different set of tools. This is how Yupik assessment of weather is said to differ from the scientific one, grounded in temperature, pressure, etc. Krupnik explains that:

> Unlike scientific weather monitoring, the Yupik [weather] watch is focused upon specific signs that signal shifts from one phenomenon, condition, or weather and ice regime to a different one that can be determined by a different term. This is the primary motivation for the use of and value in multiple specific terms for every combination of environmental conditions. The more words (and combinations) one knows, the more precise one's observation and forecast may be (2002:176).

In comparing the traditional and scientific knowledge of sea ice, Druckenmiller notes: "Hunters' real-world, place-based knowledge hastens science to focus on the importance of local processes… Their interest in accurate "science" is not a profession, but rather fundamental to sustaining traditional ways of life (2011:10)."

For the majority of communities within the PacMARS region, traditional knowledge of sea ice is yet to be documented. To date, one Yupik and one Inupiaq sea ice dictionaries have been completed, representing the areas surrounding Gambell and Wales, respectively (Oozeva et al 2002, Weyapuk and Krupnik 2012). In the former, 99 documented Yupik terms for marine ice and related phenomena are accompanied by an English translation or description and hand-drawn illustrations made by project advisors. In the latter the terms are inscribed upon the corresponding features seen in the panoramic photographs taken around the Wales area. Both works include contemporary and historical narratives of local sea ice observations that offer very instructive descriptions of the methods used, which can be applied in similar endeavors. Partial vocabularies have been documented in Wainwright (Kassam 2009, Nelson 1968, 1969), Barrow (Eicken 2010, Druckenmiller 2011), and Shishmaref (Wisniewski 2010a). Wisniewski's work in Shishmaref indicates that with the language shift, English-based sea ice vocabularies are emerging alongside or in place of the Inuipiaq ones. It is important to continue documenting local vocabularies, in the indigenous languages and the specialized English terms. The demonstrated place-based nature of the Yupik and Inupiaq sea ice knowledge warrants its documentation at community level.

C7.3 Studying and understanding subsistence

Scholars who study cultural systems tend to uphold an inclusive understanding of subsistence as a comprehensive milieu of beliefs and practices that are fundamental and to one's identity, relations with others, conception of the total environment, and sense of being in the world. These disciplinary perspectives are consistent with the Alaska Native definitions of subsistence "as 'our culture,' 'our way of being,' 'our life'" (Wheeler and Thornton 2005). Indigenous Arctic residents, especially in the regions where oil and other types of industry have substantially increased opportunities for wage employment, are adamant in countering the mistaken perception that cash economy serves either to eliminate the need for subsistence or turns it into a hobby – something that is "extra" rather than essential (Bodenhorn 2006). A consistent theme in social impact assessments is that "despite much change in rural communities in the second half of their twentieth century, the cultural value of subsistence has persisted as an essential organizing element of Native culture and community…" (Braund and Moorehead 2009:112). Research in comparative socioeconomics of the Alaska North Slope finds that throughout the history of wage employment, the income earned by the Inupiat went in great part to support subsistence. Individuals who have less time to hunt and fish because of jobs were found to harvest resources "more efficiently with the purchase and use of all-terrain vehicles, faster snow machines and bigger boats and motors" (ibid.:30). Through the decades of rapid, far-reaching change, "subsistence – along with sharing and kinship – remained central Inupiat values" (ibid.).

Integral to the holistic valuation of subsistence is a more connected view of the environment, not specifically made up of such domains as "marine," "terrestrial," "social," "natural," "empirical" and "non-empirical" (cf. Burch 1971). Indigenous cosmologies have rigidly structured and complex geographies, populated by many layers, dimensions, and kinds of landscapes. Indigenous worldviews in the Arctic render animals as non-human persons (Fienup-Riordan 1994). It is one of the core beliefs that guides both the technical and spiritual practices connected with hunting. Certain animals are emulated as teachers. Arctic seal hunters, as well scholars studying the techniques of hunting and processes harvested animals, note many similarities in the approaches and skillsets used by polar bears and humans (Lowenstein 1981, Nelson 1969, 1981). In some cases local foragers may share in the vocabulary that designates certain resources as *terrestrial*, *aquatic*, or *marine*, but not set them as boundaries of their own subsistence adaptation. The marine and terrestrial continuity is evident in the way hunters observe parallels in the behavior of animals in the marine and terrestrial niches and transfer the skills developed initially in one kind of habitat to apply successfully in the other. The emergence of the beluga hunt around Eschscholz Bay, the easternmost extension of Kotzebue Sound, is connected as much with the favorable coastal and marine geography of the area as with the resident expertise in communal caribou hunting. The experience of driving caribou on water and land, and the perceptiveness of the common features between caribou and beluga, made "traditional inland/coastal seasonal migrants the leading hunters of belugas on Kotzebue Sound" (Lucier and VanStone 1995:11).

Alaska Department of Fish and Game (ADF&G), Bureau of Ocean Energy Management (BOEM), and U.S. Fish and Wildlife Service (USFWS) are among the agencies that conduct or underwrite programs in baseline research on subsistence in the PacMARS study region. Building on the holistic framework of understanding subsistence as a cultural system, such efforts typically incorporate quantitative assessments associated with harvesting activities and principles of harvest distribution for particular species in each community. The dietary roles of species are determined based on the percentage parts of the overall food intake. Kivalina represents one of the most comprehensively and frequently surveyed villages in our study region and in all of Alaska (Burch 1985, Kruse 2011, Magdanz et al. 2010). One or more subsistence harvest surveys for Kivalina are available for every decade since the 1960. A 1985 report by Burch compares two surveys conducted over two-year periods, 1964-66 and 1982-84, finding "surprisingly few changes" between the overall harvest amounts of the two periods. However, the surveys also show great differences in harvests of specific resources existing from year to year. For example, in 1964-1965 Dolly Varden accounted for 28% of the total subsistence harvest, and only 7% of the harvest in the following year. In that latter year, residents of Kivalina were able to compensate for the record low harvest of Dolly Varden with a larger harvest of caribou (Burch 1985, Kruse 2011).

While fewer points of harvest and distribution data are available for other communities, examining how certain categories of data compare between communities unearths distinctive features. For example, in Buckland, fifteen key species of fish were found to account for 90% of the community's fish consumption, which on average is twice the number reported by the region's other communities (Magdanz et al. 2010). The 1994 survey conducted in Wales showed that bowhead whale, bearded seal, ringed seal, and walrus accounted for 78% of the overall harvest (Magdanz et al. 2002). The subsistence research in Wales illuminates the role of "super-households" in food security on the community level. The "super-household" concept is based on the ideas that (1) subsistence is often a collaborative enterprise and (2) the amounts of the subsistence resources harvested vary and can differ substantially among individual households. In Alaska, super-households are defined as those in a community that harvest at least 70% of resources. Wolfe (1987) showed that their number averages at 30% overall. In Wales, the super-households constitute 20% of households, while nearly all the households in the community show to be part of the super-household distribution network (Magdanz et al. 2002).

The year-to-year variability in the types and amounts of harvested resources and the social mechanisms of distribution inherent in the procurement of subsistence resources are the essential parameters to be considered in contemplating the human environment within the broader ecosystem change. Those parameters bring a range of uncertainties to our ability to assess how climate change interacts with subsistence, let alone make predictions about the impact of future changes. Of course the local people who are constantly monitoring the weather and ecological conditions are the ones who are most perceptive of the changes in the environment. However, the rate of the current change can overwhelm the forecasting capacities that have been used successfully in the past. Accelerating coastal erosion, more frequent and severe windstorms, rapid depletion of sea ice, and the appearance of new species are the experiences related throughout the recent body of local observer testimony (Markon et al. 2012). Commenting on the attempts to develop a system of indicators for a regional subsistence observation system, Kruse emphasizes that "given the number and diversity of arctic changes observed, and the number of possible causes, it is clearly unreasonable to expect even the most knowledgeable observers to predict the cumulative effect on subsistence harvests" (2011:17). If we align with the indigenous definition of subsistence as a cultural whole, the scope of complexities expands to a far greater set of social-ecological interactions than just the harvest and distribution parameters, which in and of themselves are very complex.

C7.4 Who "knows?" Identifying local expertise

Not long ago, outside of select fields of social science, the scholarly world by and large had little awareness of the importance and advantages of considering the knowledge of people whose everyday experience, ancestral heritage, and identity are intricately entwined within the environments that are subject of the research. Today, this is no longer the case and it is probably fair to credit the Arctic research community for being at the forefront of learning from the sphere of the traditional ecological knowledge. In certain cases, the local insight is being applied primarily to guide the logistics and locations of biological sampling (Jewett et al. 2008), however, the PacMARS study region offers prominent examples of engaging the expertise of local and indigenous knowledge in environmental monitoring and research (BOEM 2012, Gearheard et al. 2013, Eicken 2010, Huntington et al. 2009, Huntington et al. 2010, Huntington et al. 2013a, Huntington et al. 2013b, Huntington et al. 2013c, Kapsch et al. 2010, Markon et al. 2012, Norton 2002, Whiting et al. 2011). Huntington et al. explain:

> Many of the methods for collaborative research come from the social sciences, where research about or with people is the norm. These methods may not be as familiar to the physical and biological scientists, but they can be learned. It is important to remember that the interaction is a social one, involving not just the information being discussed but also the personalities, perspectives, and histories of those involved. In other words, research of this kind consists of forming a relationship, which may be brief or lasting, with all the give and take that the interpersonal relationships typically involve (2009: 347).

Among the illuminating results are also some words of caution. One is connected with the use of local knowledge in ecosystem modeling has to do with a tendency to reduce the complex descriptions that local residents draw of their ecosystems to "a few single indicators or evaluations of the 'ecosystem health'" (Huntington et al. 2013c; see Berkes and Folke 1998, Cajete 2000, Cruikshank 1998, Huntington et al. 2005, Ingold 2000, Basso 1996, Johnson and Murton 2007, Nadasdy 2004, Wheeler and Thornton 2005 for discussion of bridging ontological divides between local knowledge, natural science, and social science; see Kalland 1994 for discussion of definitions of indigenous and local knowledge; see Neis 2011, Ounanian 2013 for discussion of bridging knowledge systems in the study of fisheries and marine ecosystems; see Gasalla and Diegues 2011 for a discussion of "ethno-oceanography" framework). Whiting et al note that "Since the early description of TEK, the methods of eliciting and analyzing TEK have become more and more sophisticated, yet the most insightful analyses of TEK never lose sight of the context in which TEK is produced" (2011:2). We should also be cautious in transplanting concepts from one knowledge system to another. Huntington et al. 2013c provide the example of the Yupik word "cooking" being used as an equivalent of "hot spot," in references to locales where several species of animal and birds feed together on shared schools of fish. Whereas the Savoonga participants reported presence of "cooking" spots around Saint Lawrence Island, no other participating community talked about "hot spots." Remaining attuned to the ecosystem links drawn from local observations will likely illuminate new connections. Huntington (1998) recalls his initial skepticism, when during the research on the traditional knowledge of beluga his Native consultants would talk about beaver. Until they explicitly pointed out that the relationship between the increasing beaver populations and the damming of streams where types of fish beluga prey upon, spawn, he had thought the discussion was straying too far from the intended focus. Influx of beaver is a widely documented concern (Kruse et al 2004), which was brought up by community representatives at the PacMARS meeting in Nome.

Recent approaches show a paradigm shift from studying the local knowledge of a specific environmental domain to exploration of relationships between two or more species, including the human-animal relationships, such as Robard's (2008) analysis of the human-walrus dynamics and Wisniewski's (2010b) phenomenological take on hunter interactions with bearded seal. This framework arises from studies in indigenous epistemologies that regard animals and other components of the environment as sentient beings (Anderson 2000, Fienup-Riordan 1994, Inglod 2000, Vitebsky 2005). The Whiting et al. (2011) account in indigenous ecology of the Kotzebue Sound shares the belief about harbor porpoises working as shepherds to orcas, herding beluga for them. Sakakibara (2010) uses the term "cetaceousness" to refer to the sentient ecology of the whaling communities in northern Alaska. Merging "cetacean" and "consciousness," cetaceousness encompasses all practices and beliefs manifesting the Inupiaq awareness of the interrelationships between climate change, hunting strategies, harvest distribution, and regulatory regimes affecting bowhead whaling. Cetaceousness is aligned with the contention that "Inupiaq knowledge about a species reflects its cultural importance – or, more accurately, its cultural biography, or how the species characteristics and the livelihoods of the Inupiaq have become intertwined" (Whiting et al 2011:13, emphasis theirs).

Let us consider an example from a Shishameref-based SIWO observer (http://www.arcus.org/search/siwo, accessed 09/2012 – 06/2013). Relating how the seasonal migration and diet of seals interacts with ice and weather conditions, hunter access, and human food security, the observations illuminate the density of local ecological knowledge that is grounded in a particular set of cultural values and lived experience. The observer's vantage point is continuously fluid, shifting between the hunter activities, the ice and weather conditions, and the drying racks for the meat and hide, where the relative fullness or emptiness of the last is referenced as a multi-vocal indicator of the interrelated social and environmental processes. This is but one demonstration that "Inupiaq knowledge is rarely expressed without reference to multiple influences, because it is highly contextualized and based on individual and collective experience" (Whiting 2011:17).

When scientists interested in questions of marine mammal anatomy, diet, and health turn for insight to local experts, they tend to work primarily with experienced hunters. It is true that hunters are involved in ongoing observations of weather, ice and ocean, and animal movements. However, those on the receiving end of hunting and fishing products (processors, seamstresses, cooks) also have their way of knowing the marine environment. As Burch assertively states, "every Inupiaq woman was a professional seamstress" (2006:230). This point is underscored in an ethnohistorical reconstruction focused on the Inupiaq parkas, said to connect hunters (men/husbands), seamstresses (women/wives) and animals (Martin 2001). "Some ugruk [bearded seal] bottoms were tough and hard to put holes into… The beluga skin under the maktak is the stronger one," teaches Dorcas Neakok of Point Lay (Yarber 2012:14). The mastery of transforming harvested animals into clothing, tools, and other usable objects comes with the awareness of the physical properties of the material, which in turn rests on expertise in the animal physiology and skillful dissection (Lincoln 2010). The knowledge of such experts is in their awareness of the parameters (for example, animal health, sex, age; season and location of harvest), which contribute or detract from the workability of the raw material for the task at hand. Engaging them as research partners can help extend the overall understanding of marine mammals beyond the observations made by hunters.

At the PacMARS meetings with community representatives, participants pointed to the importance of considering the sensory dimension of local knowledge. In the context of understanding the health of the marine environment, the information that can be discerned through smell is especially relevant. The

Bering Strait hunters listed “rotten smell (even when alive)” as the primary indicator of a pathology in seals and walrus (Gadamus 2013:6). The condition known colloquially as “stinky whale” is also diagnosed through smell. Incidences of stinky whales were being noted as early as 1960s, but since the late 1990s the rate of hunters reporting encounters with gray whales that have strong medicine-like odor have been on the rise. In some cases the odor was detected from a distance – in the whale’s breath – and in other cases it was noted during butchering or cooking (Rowles and Ilyashenko 2007). Smell is also used as an indicator of seasonal processes. For example, the Wainwright representative at the PacMARS meeting in Barrow said that during the month of September, slush ice brings krill wash-ups, which are large enough to be smelled from afar.

C7.5 Grasping social-ecological change in the coastal Arctic

One of the findings of the Bering Sea Sub-Network is that the people whose everyday activities are connected with sea ice have a heightened perception of change. When observations of the coastal and inland communities are compared, the former shows to have greater sense of awareness of being affected by changes (Gofman and Smith 2011). The importance of sea ice in the values of the coastal Arctic residents is underscored by the sustained prominence of this subject in numerous “scoping” meetings, testimony, and community-based discussions. It stands out as a principal development-related concern in the statements that span over four decades of recorded testimony. Concerns related to sea ice come up in the assessment studies conducted in the 1970s (Pedersen et al. 2009) and are being voiced just as strongly in the present-day discussions of the National Petroleum Reserve of Alaska Subsistence Advisory Panel (Agnasagga 2012). Sea ice came up prominently in the statements made during the PacMARS team meetings with community representatives. In a certain category of concerns, we see a great degree of continuity. It focuses on the interactions of sea ice and oil, how sea ice functions in case of a spill, and on how sea ice is impacted by exploration activities or infrastructure. However, ways in which people talk about the ice within this persistent category has changed notably. In the 1970s and 1980s, when talking about sea ice, Arctic residents tended to accentuate its might. Here is an example statement: “When the ice is coming in with 100 million tons of force, coming right at you along with the current and the wind, nothing can stop that” (Matumeak cited in Pedersen et al. 2009). The more recent testimonies emphasize the fragility of ice and carry a sentiment of nostalgia for the thicker and stronger ice of the past years. Evidence of this nostalgia comes through in the statements of hunters who emphasize that fewer reliable ice landings are forcing them to focus on harvesting smaller whales (Brinkman et al. 2011, Kemp 2011).

Local observers, including the contributors to Sea Ice for Walrus Outlook (SIWO) (http://www.arcus.org/search/siwo, accessed 09/2012 – 05/2014) indicate that effects of climate change are manifested differently at local scales. This assertion parallels earlier noted scholarship on the place-specific nature of the coastal icescapes. Nevertheless, the common emerging patterns of later freeze-up, earlier breakup, depletion of multi-year ice, and longer ice-free periods in coastal zones are noted by local observers throughout our study region (Bogoslovskaya 2013, Brinkman et al. 2011, 2012, 2013, Carouthers et al. 2013, Druckenmiller 2011, Gearheard et al. 2013, Kapsch et al. 2010, Quakenbush and Huntington 2010, Voorhees and Sparks 2012). Throughout the region, hunters find that accessing key subsistence species has become more difficult (Brinkman et al. 2011, 2012, Carouthers et al. 2013 Gadamus 2013, Gofman and Smith 2011, Kemp 2011, Kapsch et al. 2010, Sakakibara 2010, Wisniewski 2010a,b).

While hunters may ultimately feel satisfied with the final outcome of a specific season or activity (Galginaitis 2009), their goals are accomplished in the face of the increasing travel distances endured in rougher and less predictable conditions (Gadamus 2013, Gofman and Smith 2011). Kapsch et al (2010) found that since 1980s the travel radius for the Saint Lawrence Island walrus hunt has increased by around 90km, now being near 200 km (Kapsch et al. 2010). Kaktovik and Wainwright similarly report longer travel needs (Brinkman et al. 2011, 2012). Community representatives at the PacMARS meetings framed this issue as a concern over both fuel costs and hunter safety. Wisniewski (2010b) found that until recently Shishmaref hunters preferred to travel with snow machines onto the ice and catch seals through the small openings. With the diminished thickness of today's shorefast ice, this option is no longer available.

The sea ice change is a catalyst of other social-ecological changes. Two regional research initiatives – Bering Sea Sub-Network (Fidel et al. 2012) and the Kawerak Ice Seal and Walrus Project (Gadamus 2013, Kawerak, Inc 2013) – studied the community-based perspectives on the impacts of shipping noise, expected to increase with the expanding traffic activity in the Pacific Arctic. Both studies documented insight from seal and walrus hunters, who stated that marine mammals have acute sense of hearing, communicate with sound, and equate certain noises with danger. The two studies also involved efforts of mapping traditional subsistence territories (Kawerak, Inc. 2013). In both cases, the concluding recommendations state that ships should stay in the designated lanes where they are thought to have less noise impact on the areas that are critical for subsistence. The Bering Sea Sub-Network found that overlaid maps on the marine hunting areas and the shipping lanes are useful to communities and agencies in the participatory decision-making (Fidel et al. 2012).

The subject of coastal erosion figures prominently in the discussion of the vulnerabilities posed by the contemporary coastal adaptations. At our regional meetings, representatives of traditional councils related that viability and wellbeing of their communities are threatened by coastal erosion. Several meeting participants credited their ancestor wisdom for carving out such a multi-faceted adaptive niche in Arctic coastal living, while at the same time voicing concern that the subsistence advantages chosen by their ancestors are now being compromised by the changing climate. Prolonged seasonal exposure to storm waves in the absence of shorefast ice, combined with the escalating rate of thawing permafrost, accelerates the rate at which many coastal settlements lose portions of their shore to the ocean. Coastal erosion and thawing permafrost further tie into the challenges for subsistence through the loss adequate beach for processing the catch (Sakakibara et al. 2010) and safe storage and preservation of the harvested products in the ice cellars (Brubaker 2010, 2011). Several communities in our study region are facing the hardship of having meat supplies ruined from ground water seepage into the cellar, or cellars becoming inaccessible due to the giant inside icicles forming in the process of dripping and freezing permafrost water. Communities that are vulnerable to flooding also become vulnerable to housing shortages, because of the reluctance by programs and agencies to fund new construction or adequate repair initiatives in the areas prone to disasters. For the young families needing a place to live, the only options may be staying with relatives – often in overcrowded housing situations or move out of the village (Marino 2012). The demographic shift resulting from outmigration may, in turn, bring social and economic hardships to the community, causing gaps in the customary social and sharing networks and creating shortages of hunters and harvested resources.

The community of Shishmaref is probably the one that is featured most prominently in climate change reports (Clement et al 2013, Sommerkorn and Hamilton 2008, United States Government Accountability Office 2009). The name of the village has in recent years become ubiquitous to the discussion of the social, cultural, and monetary costs of the warming Arctic (Bronen 2012, Lixenberg 2008, Marino 2012, Schweitzer and Marino 2006). During her fieldwork in the village Elizabeth Marino (2012:16) was told repeatedly that living on Sarichef Island – Shishmaref's present location – the people feel that they are in center of the "circle of subsistence" (Marino 2012:16) and that if they will abandon the area, the animals they hunt will also go away." At the PacMARS meetings with community representatives, local participants identified the human hunter niche in their ecosystem as that of a predator. The behavior of the human predator is grounded in social values (how to hunt, where, with whom and for what purpose; which parts of the animal to take home and for what purpose) and is interdependent with other components of the ecosystem. Whereas the dynamics of marine ice and mammals imposes the burden of travel distances for hunters, coastal erosion pushes current settlements to change location or to disperse into diasporas, ceasing to exist as their own perceived "center" in the "circle of subsistence" (ibid.) (Fig.

C7.1). What are the ecosystem implications of a marine predator community being forced into disintegration?

Reflecting on his fieldwork in the Bering Strait, Krupnik recalls:

> While visiting Eskimo villages, I have had more than one occasion to listen to elder hunters tell stories of how, with the appearance of outboard motors in the 1930s, they began to hunt walrus, beluga, and gray whales from skin boats at sea. Until then, it had been impossible to chase and kill these animals using only oars and sails. But, in only two or three years, hunters had successfully picked up the new hunting method. Such rapid incorporation of technological innovation into the traditional subsistence system attests to a deeply rooted aspect of native culture: its receptiveness to reform using the entire wisdom of preceding generations (1993:198-199).

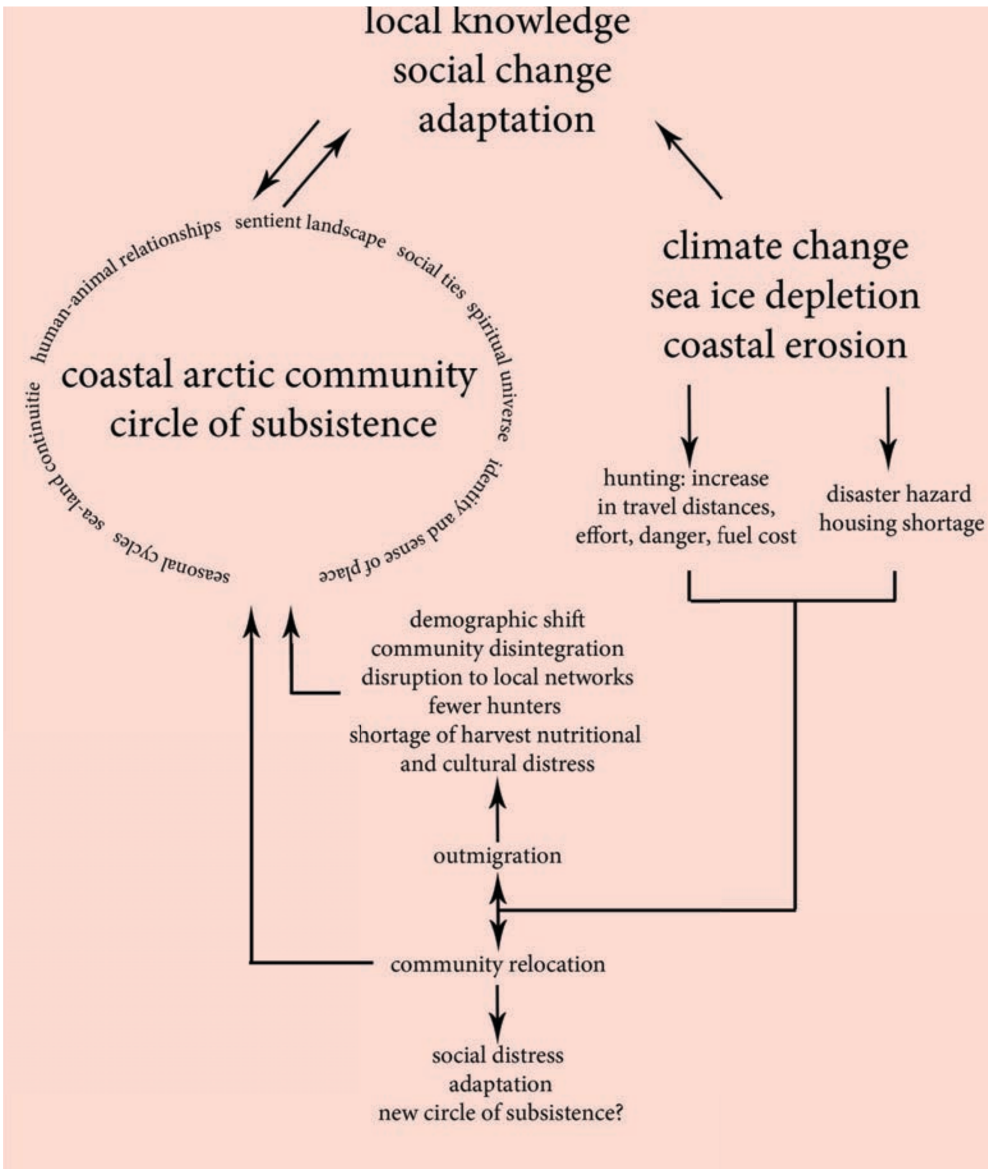


Figure C7.1 Schematic representation of interactions between climate change, subsistence, and local knowledge; arrows indicate the direction of the impact.

The history of the Arctic people is one of adaptation to many different kinds of change. The overreaching question about the current processes is whether and how well will the ever-evolving local mechanisms facilitate adaptation in the face of the cumulative impact of the interactions between social and ecological change. The liminal social-ecological space of the Arctic Alaska coastal zone is ought to remain the subject of the ongoing conversation. Among the numerous parties and stakeholders, this conversation is ought to sustain the progression of mutual interests between the researchers, studying the coastal ecosystems, and the people for whom these liminal spaces are the ancestral heritage and the lifelong home.

C8. Consensus Input from Local Subsistence Communities in Alaska

As part of the overall goals of PacMARS, the PacMARS team conducted five regional Alaskan community meetings on St. Lawrence Island, and in Barrow, Kotzebue and Nome (Table C8.1). The meetings provided a forum for feedback on research needs as they are perceived by local communities as well as for ecological insights from subsistence hunters specifically and local residents in general. Two of the community meetings (Gambell and Savoonga) were conducted as formal open community style meetings. The other meetings were "hub" style meetings with representatives selected by the Indian Reorganization Act (IRA) Councils that serve as tribal governments for each village represented. Representatives from Wales, King Island, and Point Hope were unable to attend. Comments contributed at each village meeting contained in this report have been edited for clarity, but represent the opinions expressed at each meeting by participants.

Table C8.1 Date, location and communities served at PacMARS regional community meetings**.**

Date	Meeting Location	Communities Represented
January 28, 2013	Savoonga	Savoonga
January 29, 2013	Gambell	Gambell
February 11, 2013	Barrow	Barrow, Wainwright, Point Lay, Nuiqsut, Kaktovik
February 22, 2013	Kotzebue	Kotzebue, Point Hope (representative unable to attend), Buckland, Kivalina
February 25, 2013	Nome	Nome, Diomede, Wales (representative unable to attend), King Island (representative unable to attend) Brevig Mission, Teller, Shishmaref

The PacMARS community meeting objectives included:

- To provide an explanation of the PacMARS effort
- To give updates on research in the respective areas
- To discuss marine issues important to the communities including gaps for future study
- To discuss useful ways of communicating science results
- To identify good examples of regional knowledge and western science working together

The following summary outlines a composite narrative from the "hub" meeting report that includes comments on marine issues and suggestions by local coastal community members for future research needs and communications in the Pacific Arctic region. The full report is provided in Appendix G8 (Grebmeier (ed.) 2014) and is also available on the PacMARS website (http://pacmars.cbl.umces.edu).

C8.1. Key science themes and topics from all community meetings

A consensus set of topics that were brought forward in all the community meetings included two overarching themes: a. Security and Stability of Subsistence Resources, and b. Communications and Engagement. Within the subsistence resources theme, marine mammals and seabirds, fishing, and hunting were key sub-topics. In addition, concerns involving oil development and mining, shipping and ship traffic, and environmental changes (ice, physics & contaminants) were identified. The second theme of communication and engagement between local communities and scientists were also clearly important topics for joint efforts moving forward.

C8.1.1. Security/Stability of Subsistence Resources

a. Marine Mammals & Birds

During all 5 community meetings, concerns were expressed related to marine mammals and birds. Bowhead whales, beluga whales, walruses, seals, ducks, geese and polar bears were specifically mentioned. The communities were interested in knowing how changes in sea ice, industrial maritime ship noise and traffic, contaminants/pollution events, and increased fishing pressure will affect the movement and health of marine mammals. The communities would like programs in place to monitor changes in the migratory patterns and timing of marine mammals, fish, and seabirds. All 5 community meetings brought forward concerns about the recent federally designated Northern Alaskan Pinniped Unusual Mortality Event, a disease of still unknown origin that has produced skin lesions and other physical and behavioral symptoms to 4 species of ice-associated seals as well as walruses. Communities would like to know what is comprehensively known about the disease.

b. Fishing, Hunting & Food

In all 5 community meetings, concerns were brought forward about trawling and large-scale commercial fishing operations. While the Bering Sea is considered productive, commercial fishing is beginning to move to more northern areas, according to our community representatives. There was general concern about not only the species being fished, but also the impact of trawling on benthic communities as well as the larger organisms that depend on them for food (i.e. clam beds and walruses). Local community authority through sovereign tribal governments ends at the highwater mark, so subsistence communities are concerned about how subsistence conflicts with industrial-scale fishing will be resolved. During all five community meetings, strong concerns were expressed about toxins in local marine food resources and how toxicity and contaminant levels - be studied in subsistence foods now and in the future

c. Oil & Mining

During all five community meetings, concerns were expressed about oil drilling as well as both offshore and onshore mining activities. Communities are concerned about the spill response infrastructure, and related communications (i.e. regional, state-wide, international), response training, and finances.

d. Shipping & Ship Traffic

During all five community meetings, concerns were expressed about industrial maritime ship traffic through the Northwest Passage and Northern Sea Route. Concerns included increased noise, pollution, human safety (boaters), wildlife safety, and introduction of diseases. There was general concern that marine subsistence resources would be impacted by both industrial and other large ship traffic (i.e. large research, tourist, and/or governmental ships). The communities wanted to know how the ship traffic would impact animal and seabird migratory patterns, prey availability, and if the animals would be deflected away from the coastal communities making them less accessible/available as a food resource and/or impacting the animals directly by driving them from their critical feeding/breeding areas. They were also concerned about pollution, sewage and invasive species in water discharge from passing vessels.

e. Ice, Physics & Contaminants

During all community meetings, concerns were expressed about the effects of warmer water temperatures and retreating seasonal sea ice. Community representatives were specifically concerned about how greater open water was increasing erosion through extensive wave action and how that was affected the integrity of critical structures (roads, buildings, ice cellars), as well as loss of tundra to the ocean. The communities were also concerned about changes in ocean current patterns and ocean fronts. They asked that these processes be repeatedly measured in similar ways in order to compare and contrast conditions in time and space. The community meetings also brought forward concerns about contaminants in the environment and how changes in physical features (sea ice, erosion, melt run-off, rainfall) would affect transport and amounts of contaminants.

C8.2 Communications and engagement

During all community meetings, it was pointed out that regionally specific, community-based input is not only extremely valuable but it is also extremely under-utilized. Communities would like studies regarding the impacts of marine ecosystem changes on local regional communities, but that these studies should take a more integrated perspective. These communities consider themselves to be marine predators that are integrated with the regional ecosystem, taking and contributing to ecological processes. These communities work to minimize impacts on the environment and adjust social behavior accordingly. The community representatives pointed out the disparities between the existing marine resources regulatory frameworks and their perceived roles as human predators in the ecosystem processes.

Many meeting participants expressed interest in the idea of synthesis. They wanted to know more about the PacMARS project and suggested that flyers be distributed in villages to explain PacMARS objectives and also to give updates on the project. [Note: Some of the PacMARS PIs are currently preparing a flyer on the project to be distributed to the coastal communities]. The communities asked for tangible products in order to document a range of information including the state of the ecosystem, outcomes of meetings, outcomes of studies and the importance of subsistence resources. They suggested that clear labels be placed on scientific maps and that scientific information on slides be presented in layperson terms. The meeting participants suggested that information be conveyed in graphical format.

Meeting participants also said that explanations were needed for the relevance of any research being conducted. They suggested that regular research updates be provided on marine issues of interest at an announced time and location. The opinion was generally expressed that education and outreach should be explicitly included in research programs. Local communities would like to see their local students included in scientific research programs, research cruises and fieldwork opportunities.

Community representatives recommended that elders be contacted directly for meetings and individually for input on scientific studies and research needed. They also suggested that when researchers go out in the field, they should exchange information with local residents.

The importance of communication was brought up repeatedly, and some representatives pointed out that there needs to be a long-term communication effort between scientists, agencies, and local community members. However, this request on a scientist-specific basis is inherently at odds with the current science funding structure, which is dominated by short-term research grants that really do not lend themselves to long-time communication. When multiple projects are supported to the same scientist, the arrangements can permit longer-term communication. Funding agencies need to consider how to maintain a long-term communication channel with local communities in the Arctic while having to rotate funding support among different scientists as well as only supporting 2-3 yr. grant cycles. NPRB, NSF and BOEM, along with other federal and state funding agencies should strategically consider how to maintain continuity of community interactions within the funding limitations of their organizations.

The findings from the PacMARS community meetings were informative and facilitated a better understanding of issues facing local Alaskan communities in the Bering Strait region as well as the, Chukchi and Beaufort sea coasts.

D. RESEARCH THEMES AND TOPICS, MAJOR FINDINGS, DATA GAPS, AND DIRECTIONS FOR FUTURE STUDIES

The PacMARS team effort was based upon a consensus regarding organizing principles for our synthesis strategy (D1) and identification of three emerging research themes and related questions that were evaluated during the project (Section D2). We further refined this approach by selecting six directions to aid in research program development (Section D3). As part of this process, we identified methodological issues and approaches, data and/or knowledge gaps, and promising future research directions (Section D4). We outline here a brief summary of major findings, data gaps, and relevance of topics to local communities, provide questions for future directions associated with the six core themes, and present a conceptual model of the Chukchi and Beaufort Sea marine system to guide program development (Section D5).

D1. Organizing Principles for an Ecosystem Approach

In general, research priorities were identified through discussion and synthesis activities of PacMARS and SOAR, including our PacMARS-SOAR workshop in January 2013, the PacMARS community hub report, and the PI meeting in Anchorage in January 2014, as well as other synthesis efforts and analysis of planning documents introduced in Section A (Introduction) and tabulated in Appendix G1, the PacMARS Data Source Table. Parallel to our work, research priority identification was also a goal of the National Academies "The Arctic in the Anthropocene: Emerging Research Questions" report (National Research Council, 2014) that was released in April 2014. Other relevant recent reports that were consulted include the report of scientists who participated at meetings at the White House Conference Center in 2013 (Dickson et al. 2014), the Lowell Wakefield Fisheries Symposium in 2013, and agency reports that are discussed in the Introduction (Section A) and Methods (Section B).

The guiding strategy for our resulting recommendations is that ecosystem level integration is intrinsic to any broad scale research program, a strategy that has implications for both future research planning as well as implementation. The approach PacMARS investigators took to identify research gaps was to compile and visualize retrospective/legacy and recent data (Sections B and C). The resulting gaps were formulated into research priorities (outlined here as Section D). A diagrammatic overview of this process (Table D1), categorized the status of regional and seasonal surveys and measurements across disciplines. The "status" evaluation identified several broad deficiencies in our knowledge that extend over multiple trophic levels and categories. These deficiencies include poor understanding of most process variables outside of the summer-early fall season and over the annual cycle, and poor understanding of rate processes of the marine ecosystem for most trophic levels and seasons. Similarly, understanding the relationships among annual cycles and changes in wind and ice conditions, faunal dynamics, subsistence harvests, and well-being of human communities in the coastal zone requires a sustained support of recordkeeping activities by local observers and continuous collaboration with local communities.

D2. Broad-Scale Research Themes and Proposed System-level Studies in the Pacific Arctic

We identified three key, broad-scale, overarching research themes and associated research topics that are pertinent to successfully launch a fully integrated ecosystem research program in the PacMARS region. We do not consider these themes to meet all research needs for the PacMARS study area, but we think that many critical needs can be addressed through these three formulations. The three themes are purposely general in scope and serve as guideposts rather than strict implementation recommendations. We provide specific examples of research questions that should be addressed in Section D3. For all

Table D1. Status of knowledge of environmental, biological and human impact/use properties of the Pacific Arctic Region ecosystem as categorized by PacMARS team consensus. Note that the rating is focused on US/Canadian waters, with the overall rating of poor for access to properties in Russian waters.

Variable	**Status of knowledge: red-poor, orange-moderate, green-good**							
	Spatial		**Annual time period**			**Seasonal time periods**		
	Region-wide coverage		Time series (year to year)		Winter	Spring	Summer	Autumn
Water mass properties								
Temperature	green		orange		orange	orange	green	orange
Salinity	green		orange		orange	orange	green	orange
Stratification	green		orange		orange	orange	green	orange
Heat content	green		orange		orange	orange	green	orange
Freshwater content	green		orange		orange	orange	green	orange
Biotic abundance/biomass, distribution and diversity from science and local knowledge								
Microbes	red		red		red	red	red	red
Microalagae / Chl a	green		orange		red	orange	green	orange
Microzooplankton	red		red		red	red	orange	orange
Mesozooplankton	green		red		red	orange	green	orange
Gelatinous zooplankton	red		red		red	red	orange	orange
Benthic meiofauna	red		red		red	red	red	red
Benthic macrofauna	green		orange		red	red	green	red
Benthic epifauna	green		orange		red	red	green	green
Macroalgae	orange		orange		red	orange	orange	orange
Fish	orange		red		red	red	orange	orange
Sea birds	green		orange		red	orange	green	green
Marine mammals	green		green		red	orange	green	green
Biological processes / rates								
Primary production (pelagic)	orange		orange		red	red	orange	orange
Primary production (sympagic)	orange		red		red	red	orange	red
Vertical flux	red		red		red	red	red	red
Secondary production zooplankton	red		red		red	red	red	red
Growth, age, reproduction benthos	red		red		red	red	red	red
Respiration, remineratization	orange		orange		red	red	orange	orange
Growth, age, reproduction fish	red		red		red	red	red	red
Thermal tolerance windows for biota	red		red		red	red	red	red
Food web (stable isotopes)	green		red		red	orange	orange	orange
Diets for variable trophic levels	orange		red		red	orange	orange	red
Marine mammal body index / health	green		orange		red	orange	orange	orange
Sediment properties								
Grain size	green		orange		orange	green	green	green
organic content	green		orange		orange	green	green	green
C/N ratios or organic material	green		orange		orange	green	green	green
Contaminants	green		orange		orange	orange	orange	orange
Human impact/use								
Metal contaminants	green		orange		red	orange	orange	orange
Organic contaminants	green		orange		red	orange	orange	orange
Biomagnification and bioaccumulation	red	red	red		red	red	red	red
Noise	orange		orange		red	red	red	red
Species invasions (incl. local knowledge)	red		red		red	orange	orange	orange
Food security indicators	green		orange		red	red	red	red
Subsistence harvests	green		orange		orange	orange	orange	orange
Cumulative impact effects	orange		orange		orange	orange	orange	orange
Ecosystem/human resilience/adaptation	orange		orange		orange	orange	orange	orange
Management and conservation strategies	orange		orange		orange	orange	orange	orange

themes we stress that their consideration over a range of spatial and temporal scales is critical, but challenging to address. Rapidly advancing technologies can help fill some of the identified gaps. Note that our focus is on the eastern Chukchi and Beaufort seas due to limited data availability in the Russian sector of the Chukchi Sea.

Theme 1: Impacts and connectivity of advective physical forcing and changing ice cover on ecosystem structure

Sub-theme: Advection
Advection is a key forcing function for the Arctic marine system in general and the Pacific Arctic region in particular. Advection through the Bering Strait creates the nutrient, plankton and organic carbon detrital "highway" that connects the Bering Sea to the Chukchi Sea and further to the Beaufort Sea and the Canada Basin. Advective northward flow of productive waters from the northern Bering Sea across the Chukchi Shelf and ultimately into the western Beaufort Sea can therefore be viewed as an extension of the eastern Chukchi Sea both in terms of physical oceanography and from a biogeographical viewpoint. Connectivity between these seas is modulated by shelf-break vorticity-constrained and buoyancy-driven currents. In addition to advective supply of nutrients from southern areas, productivity in the Beaufort Sea is strongly tied to upwelling along the slope. Short-lived eddies (days to weeks) produced at the shelf break are also connecting shelf and basin by transporting dissolved and particulate materials both on to the shelf or off into the deep Arctic basins, whereas long-lived (months) eddies are found only in the basin. Nearshore waters, in contrast, are influenced by large fluxes of riverine freshwater and terrestrial carbon input. As one biological example of differential connectivity via advection in the Pacific Arctic is the transport of krill, which are carried from the Bering Sea through the Chukchi Sea primarily within Bering Sea Winter Water. There are indications that krill likely overwinter on the Chukchi shelf but do not appear to establish endemic populations. Krill washed up on the beach at Barrow in July most likely would have had to overwinter on the shelf, given the several month transit time of winter water from the Bering Sea to Barrow. Krill also have been observed under the sea ice in Barrow during winter.

Subtheme: Sea ice Decline
Inherently connected to advection, sea ice is a primary forcing factor in the PacMARS region and should be jointly considered in the context of advection. The Chukchi Sea is among the most vulnerable Arctic continental seas for ecosystem change, which has been mediated by the steep decadal decline in seasonal sea ice present in its waters; extensive proportions of shelf waters are now ice free in late summer of most years. The proximity to subarctic ecosystems enhances the potential for invasive species establishment. The temporal and spatial patterns of sea ice production and melt are critically connected to atmospheric and ocean forcing and resulting patterns in ecosystem response. For example, northeast prevailing winds in the northern Chukchi Sea lead to sea ice and ice melt water persisting over Hanna Shoal and in Barrow Canyon, with strong vertical stratification. By contrast, winds from the south re-distribute sea ice northward and diminish stratification. As sea ice diminishes, fewer occurrences of a highly stratified northern Chukchi Sea system are likely. Similarly, the presence of sea ice attenuates light penetration within the water column and mediates momentum, gas, heat and evaporative exchange between the atmosphere and the ocean surface.

Phenology and extent of ice coverage are thought to regulate carbon partitioning between pelagic and benthic realms as well as impact life cycles of organisms that depend upon sea ice as habitat (e.g., walruses hauling out over the shallow continental shelf; also treated in Theme #2 below). Uncertainties include the connections between changing ice cover and physical forcing. The implications for biological communities are beset with complexities that cannot be addressed adequately at this time. Limited knowledge of winter processes and even standing stocks hinders our ability to correctly model production cycles. For example, it is thought that processes in the poorly known winter period can influence primary production rates in spring as well as the overwintering survival of plankton species.

Key uncertainties include, but are not limited to:

- What is the regional variability (time and space) between chlorophyll biomass that is advected from upstream production vs. locally produced primary production?

- What is the activity level and survival of biota during the sea ice-covered and/or dark season in relation to circulation, hydrography, ice cover, and regional gradients in forcing?
- What are the physical and biological mechanisms by which winter processes drive production in spring in a region-specific context?
- How will nutrient cycles and nutrient availability be affected by changes in ice cover and climate?

Theme 2: Phenology shifts as tipping points for ecosystem functionality

Differences in physical and biological phenology across the Pacific Arctic region reflect system-level gradients, but spatial and temporal gaps in knowledge currently limit our understanding of ecosystem process and connectivity. Climate induced changes in the phenologies of key linked processes such as zooplankton reproduction and grazing in relation to that of ice algal/phytoplankton blooms were identified as key areas needing future study. Interlinked with this research need is the possible northward expansion of migratory or advected species with life histories that may or may not match future seasonal cycles. We thus need to identify mechanisms that could force system-level reorganization of the ecosystem related to shifts in phenology in the future.

In order to address match and mismatch-related questions that revolve around production and consumption cycles, zooplankton and benthic rate measurements and eco-physiological measurements are needed to constrain temperature-dependent growth rates and thermal tolerance ranges for Arctic zooplankton species. Within these needs are modeling approaches that include incorporating physical, biochemical, and biological processes as well as network modeling approaches.

The phenology of biological processes and reproductive cycles and their variability related to gradients in physical forcing are clear knowledge gaps. It is possible that fundamental ecological re-organization could be a response to changing physical conditions and that these changes could include contaminant cycling. Temperature-dependent measurements of growth and production of biota are also sparse, but are critical to establish temperature tolerance and optimum ranges for Arctic biota.

Key uncertainties include, but are not limited to:

- How does the timing of ice retreat affect phenology and the reproductive strategies of many zooplankton species that are timed to take advantage of ice algal/water column phytoplankton blooms?
- How does the timing of transport, reproduction and other processes change as physical conditions vary?
- Can we explicitly measure and model south-to-north differences in phenology? What are the time and space complexities?
- How does the cold pool in the northern Bering Sea impact downstream processes in the Bering Strait/Chukchi Sea ecosystem complex?
- What are the linkages between various contaminants and migrating animals and biomagnification patterns?
- What are the abundances and distributions of the undersampled components of the ecosystem (microzooplankton, megazooplankton (e.g., gelatinous zooplankton), and meiobenthos) that are essential components in the food web and biogeochemical cycling?
- What are the modeling needs to incorporate physical, biochemical, and biological processes, and to take into account food web network structures?

Theme 3: Dynamics within the nearshore zone

The nearshore zone (distance <20 nautical miles from coast) is the interface between human/biological communities and offshore ecosystem processes: it connects terrestrial biogeochemical systems to marine waters and oceanic carbon cycling. The coastal domains extending from the northern Bering Sea to the Beaufort Sea are shallow and warm through the spring breakup to fall season, with seawater temperatures colder to the north, and along the Beaufort Sea coast. Along the northwest coast of Alaska, local communities use the coastal ocean within 10-20 km from shore, a region under the influence of the Alaska Coastal Current in the Chukchi Sea and river inflow in the Beaufort Sea. Northern Beaufort Sea coastal communities such as Kaktovik and Nuiqsut, are particularly dependent on subsistence food resources that inhabit estuarine lagoons and coastal habitats inshore of the barrier islands. These estuarine lagoons are important focal systems at the land-sea interface and include critical habitat for numerous species, including migratory fish and waterfowl. Compared to the middle and outer shelf, the nearshore zone of the Arctic is inaccessible to deep-draft oceanographic vessels and icebreakers and thus is relatively understudied, and consequently, we have a very limited understanding of ecosystem dynamics in these lagoons. For some areas, where decadal time scale observations exist, dramatic environmental change is occurring (e.g. ice retreat, coastal warming, landscape greening, increased coastal erosion). Current observation capacities in arctic coastal environments are, however, widely recognized to be inadequate.

It is well recognized that needs are urgent to improve our understanding of interrelated biophysical changes as well as the resulting potential impacts to society, biota, as well as the fate and transport of carbon, water and energy within the Arctic and beyond. Several recent studies highlight these tight linkages, such as how changes in sea ice extent can impact terrestrial processes (e.g. Bhatt et al., 2010), control coastal erosion (e.g. Aguirre 2011) and how sea ice extent influences the transport of carbon, water and nutrients to nearshore estuarine ecosystems (e.g. Mathis et al. 2012, Pickart et al. 2013). In addition, other work in arctic coastal lagoons has demonstrated that nearshore waters are more productive and resilient than previously recognized, sustaining year-round benthic invertebrate populations that support complex food webs (Dunton et al. 2012). Nearshore estuarine environments in the Arctic are critical to local coastal fisheries (von Biela et al. 2013) and also serve as habitat for hundreds of thousands of birds representing over 157 species that breed and raise their young over the short summer period (Brown 2006). However, this ecosystem is particularly sensitive to reductions in pH due to rising atmospheric CO_2 levels and increased organic matter respiration driven by warming and changes in the hydrological cycle (Hu and Cai 2013).

Current observational capacities in arctic coastal environments are widely recognized as inadequate. To improve our understanding of the arctic estuarine system we must enhance capacities for integrating and synthesizing spatio-temporally diverse data from observing platforms spanning the terrestrial, nearshore, and shelf domains. Constraints of funding and logistics have prohibited continuous and widespread observing capacities throughout the Arctic. There exists a clear need for a few well-conceived and orchestrated '*flagship observatories'* that support a dense and diverse range of observing programs capable of monitoring environmental change and variability at strategic locations on synoptic time scales (NRC 2006, SEARCH 2014-see http://www.arcus.org/search-program). Flagship observatories have proven capacities and efficiencies in the Arctic, as exemplified by the synergistic and complementary information provided by the Distributed Biological Observatory (DBO) on the Chukchi Sea shelf (Grebmeier et al. 2010). However, no such efforts have been employed in the nearshore zone of the western Arctic, despite the nature and potential implications of observed changes that have taken place in this region over the past decade

Key uncertainties include, but are not limited to:

- How will changes in sea ice conditions influence coastal erosion?
- What impacts will warming or changes in freshwater runoff into coastal waters have on trophic dynamics?
- How will continued sea ice retreat impact availability and accessibility of essential marine resources for subsistence purposes by coastal communities?

- How will changes in the relative inputs of marine vs. terrestrial organic carbon influence trophic dynamics, including fish and shorebird species harvested for subsistence?
- How will changes in water quality parameters, particularly temperature, salinity, and pH that are coupled response indicators of a warming Arctic, vary across the region in the future?
- How will the diversity, abundance, and interannual variability of benthic fauna respond to decreases in pH associated with local runoff and anthropogenic and natural increases in CO_2?
- How will the delivery of freshwater from streams and rivers affect hydrology, flushing, and circulation of lagoons, bays, and deltas?

D3. Future Science Recommendations and Relevance to Local Communities

The following text is based upon the six research foci identified at the initiation of the project. We outline knowledge gaps that have been identified following our data syntheses that resulted in the PacMARS team recommendations, including critical questions and hypotheses that should be incorporated into future research activities. The gaps and future directions are not ranked by priority in this section, but are treated as more specific implementation tools than the research themes outlined in the previous section (D2). Because of poor temporal coverage for many parameters, findings related to timing and decadal change are necessarily limited.

Recommended Research Direction #1: Evaluate the impacts and connectivity of a changing ice cover and physical forcing on lower trophic level production and carbon cycling

Major findings: Sea ice cover has diminished dramatically over the last two decades, with later seasonal freeze up and earlier break-up, near extinction of multi-year ice in the PacMARS region, and longer ice-free periods in coastal zones. In recent years these changes in extent have been quantified regionally and on a pan-Arctic scale, from every perspective ranging from local observers to satellite sensors. Warmer summer sea surface temperatures also are observed in the northern Chukchi and fresher surface salinities in the Beaufort/Canada Basin since 2005 relative to previous years. Reduced sea ice cover also increases potential uptake of CO_2, with attendant ocean acidification and melted sea ice potentially reducing surface water alkalinity. In addition, several studies indicate that Arctic sea ice itself enhances CO_2 uptake, so a continuing reduction in sea ice is likely to increase atmospheric CO_2 (e.g. Rysgaard et al. 2013).

Knowledge/Data gaps: While PacMARS and SOAR data aggregations will enable clearer studies of ecosystem impacts of sea ice reduction on a regional scale, a comprehensive, temporally and spatially explicit carbon budget has yet to be constructed that details the sources and sinks for organic matter that is advected or produced locally for the Bering Strait region, Chukchi, or Beaufort seas. Uneven opportunities for data collection have made it difficult to evaluate temporal and spatial change in relation to biological production at the lower trophic levels within a systems perspective. Multiple data gaps exist, including: (1) the relationship among seasonal and interannual coverage of sea ice and primary production, (2) impacts of sea ice changes on organic carbon uptake in biota and potential sequestration to sinks, (3) impacts of sea ice cover on the balance of pelagic versus benthic carbon pathways, (4) lack of seasonal and spatial coverage for sentinel lower and upper trophic species, and (5) erosion, and wave regime studies in the nearshore coastal zone.

Relevance to Local Communities: Sea ice is of critical relevance for human communities living in the Arctic. While the typical marine science perspective places sea ice within the construct of marine systems, indigenous geographies regard icescapes as extensions of human settlement, marked by named places, travel routes, navigation markers, geophysical characteristics, and user memories. Shorefast ice provides a dynamic substrate extension to Arctic coastal communities during much of the year. Local knowledge often distinguishes many controls on animal behavior, abundance, and distribution in relation to ice conditions. Sea ice distributions are, in turn, greatly influenced by wind, with direction and intensity of wind having an impact on weather, snow, ice movement, and hunting opportunities. Among the expected changes on the part of community residents are accelerating coastal erosion and more frequent and severe storms, increased shipping traffic and planned development of petroleum resources and the potential noise and chemical disturbances associated with both. The appearance of new species with reduced sea ice cover were another concern of local observers, and is consistent with scientific observations. The importance of sea ice to coastal Arctic residents is underscored by the sustained prominence of this subject in numerous meetings, testimony, and community-based discussions. To be effective, future research programs must incorporate local community observations, participation, and purposeful outreach and education of project results.

Potential Questions for Future Research:

- What limits primary productivity in relation to changing ice conditions?
- What gains or losses of ecosystem services can be expected with changes in ice extent, regional climate, and ocean dynamics?
- How might nutrient distributions change and how would this impact productivity?
- How will changing ice conditions change the distribution and magnitude of ice algal production and what are attendant effects on the resiliency, productivity, and diversity of Chukchi and Beaufort Sea benthic and pelagic communities?
- Will current pathways and material and volume fluxes change in the nearshore and offshore regions in relation to sea ice decline, and if so, what impacts will these changes have on prey of upper trophic level animals which are important for subsistence-based coastal communities?
- What is the impact of changing ice conditions on food web dynamics and on the resulting carbon export and sequestration to the shallow and deep oceans?
- How will changes in sea ice conditions influence the distribution, abundance, and reproductive fitness of these marine resources?
- On what regional and temporal scales will changes in sea ice conditions affect human industrial development and attendant risk for pollution?
- What impact will continued sea ice retreat have on coastal communities' with respect to availability and accessibility of essential marine resources for subsistence purposes?
- How will changes in sea ice conditions influence coastal erosion?

Recommended Future Direction #2: Understand the phenology of biological production cycles in relation to the physical environment within a changing climate

Major findings: The phenology of biological production cycles is tied to the annual cycle of light in high-latitude ecosystems. This strong signal in light availability, combined with seasonal nutrient availability, typically results in a highly focused primary production peak in spring followed by a delayed peak in secondary production later in the season. Both sea ice algae and open water production exhibit a latitudinal gradient in intensity related initially to light, but controlled by a combination of light and nutrient availability. Life cycles of Arctic animals are linked to the predictable timing of these peaks so that they can take full advantage of the extremely short growing season. The reproductive strategies of many zooplankton species have evolved to maximize their productivity during the short growing season so that they can attain a stage of development that allows them to overwinter successfully. Many higher trophic level animals (i.e. bowhead whales and seabirds) time their migration patterns to these peaks in productivity as well, as PacMARS synthesis products have documented through aggregating multi-year efforts. The recent changes in seasonal ice coverage and the concomitant increase in light transmittance implies that production cycles may be changing with earlier open water and under-ice blooms that portend to lengthen the growing season and possibly increase the total productivity of the system.

Data gaps: PacMARS data aggregation efforts have visually documented the dominance of summer (and fall to some extent) measurements over the other seasons (Table D1). Largest seasonal gaps remain in winter for essentially any variable measured *in situ*. Retrospective assessments of interannual variability are limited by shifts in spatial focus of the studies over the decades. In addition, we have limited data on the cumulative effects of changing physical forcing on the timing, magnitude, and duration of biological and biogeochemical production cycles. Knowledge gaps in responses exist both in: (1) potential changes in colonization patterns and replacement of arctic endemics by subarctic populations/species, and (2) the capability of organisms to adapt and/or tolerate change. How these changes will affect the current production cycles of the arctic endemics, the potential colonization of Pacific expatriates, as well as the migration patterns and important use areas of seasonal migrants, is an open question.

Relevance to Local Communities: Community representatives during PacMARS hub meetings emphasized their *in situ* observations and concerns, specifically that changing seasonality of the marine ecosystem has the potential to displace or reduce in abundance the prey organisms of subsistence harvested upper trophic level predators (e.g., fish, seals, whales, ducks) as well as shifting the distributions of those subsistence species themselves. They expressed concerns that a shift in the timing of biological processes and the potential replacement of Arctic endemic species by subarctic populations/species affects the nutritional, cultural, and economic well-being of coastal human communities that rely on these marine resources. Changes in timing would directly affect the accessibility and availability of marine resources to communities. Additionally, a change in the body condition of marine resources has the potential to directly affect human health as well as to exacerbate food security concerns. Range expansion by subarctic fish species may lead to the northward extension of commercial Arctic fisheries and introduce the potential for (time and space) conflicts with traditional subsistence activities, environmental disturbance (e.g. bottom trawling) and overfishing of target stocks.

Potential Questions for Future Research:

- How does the phenology and magnitude of ice algal and phytoplankton blooms and associated production vary with changing ice conditions and attendant light and nutrient conditions in different water masses and domains?
- What impact will these variable processes have on the success of secondary producers (and their predators) across the system?
- What is the environmental niche space of individual species and biological communities, including primary producers, based on hydrographic, geographical and sedimentological characteristics and species/community distribution patterns?
- What are the rates of activity and survival of organisms in the winter, how much food remains available (are "food banks" present?), and how does this impact the following spring production?
- With climate change, will colonization patterns change and will arctic endemics be replaced by subarctic populations/species at all trophic levels?
- What are the human and community impacts as well as resiliency strategies that are most likely to succeed following changes in the health and/or availability of subsistence species?

Recommended Future Direction #3. Determine the role of pelagic-benthic coupling in relation to changing physical forcing and biogeochemical shifts

Major findings: On the Pacific Arctic regional scale, general spatial patterns of high and low algal and benthic biomass appear to have persisted over the past 3-4 decades, with larger variability in zooplankton densities. On the sub-regional scale, however, PacMARS and other regional synthesis efforts document region-specific variability and/or changes, or lack thereof. Pelagic algal biomass in the southern Chukchi Sea during summers after 2004 has remained consistently high in comparison with measurements from previous decades, which likely explains why key benthic depositional areas have been relatively unchanged in this region. Substantial increases in chlorophyll biomass just north of Bering Strait and along the northern shelf of the Chukchi Sea and substantial decreases in the western Chukchi/Herald Valley region during this later period (post-2004) potentially reduce carbon export to the benthos in the west, while increasing carbon export to the benthos in the northeast. In the early 2000s, pelagic-benthic coupling was very strong in the northern Chukchi Sea and western Beaufort Sea due to high primary productivity and low planktonic grazing pressure, especially during the spring ice algal/phytoplankton blooms. Our PacMARS analyses also indicate an increase in benthic biomass in the SE Chukchi Sea as a “chlorophyll and benthic biomass hotspot”, implying an increased downstream deposition of more phytodetritus that is reaching somewhat further north. Perhaps this explains the increased level of benthic standing stock in the NE Chukchi Sea since 2005 compared to pre-2005.

Data gaps: Improved process level understanding of the impact of changing climate forcing on the strength and direction of pelagic-benthic coupling is needed. Specifically, studies should focus on the partitioning of carbon flows between the water column and seafloor, and identify key species that will be affected by the potentially changing balance in organic carbon transfer from water column to benthos. Related to this partitioning, better understanding of mechanisms driving the development and persistence of benthic and pelagic areas of high biomass and productivity and of how those hotspots interplay with biogeochemical cycles.

Relevance to Local Communities: Carbon partitioning between the pelagic and benthic realms ultimately influences how stocks of pelagic- and benthic-feeding subsistence-harvested birds, fish and marine mammals may develop over time. The strength of pelagic-benthic coupling therefore also determines the locations of dominant feeding sites and thereby indirectly controls access to preferred harvest species. Currently, benthic-feeding mammals (walruses and bearded seals in particular) are important subsistence food resources for coastal communities, and are dependent on concentrated and persistent benthic biomass as their food source. If walruses and bearded seals move further offshore or away from traditional feeding zones, these resources would become less available for coastal subsistence hunters. On the other hand, pelagic-dominated food webs could enhance abundance and/or availability of endemic or novel planktivorous or piscivorous predators for subsistence use. Timely knowledge of any regime shift would assist in adaptation actions.

Potential Questions for Future Research:

- Can we forecast how the changing environment will modify trophic structure (species community composition, species dominance) and how will it strengthen or weaken pelagic-benthic coupling?
- Will the northern Bering Sea, and the Chukchi Sea remain a benthic-dominated shelf or will pelagic secondary producers becoming increasingly prominent?
- How will similar changes influence trophic structure and biological processes in the Beaufort Sea?
- What subsistence relevant species may benefit from a potential shift from a benthic-dominated to a pelagic-dominated system in the Chukchi Sea?
- How adaptable may higher trophic level species be to potential shifts in carbon flow through foodwebs?
- How will fauna respond to changing temperatures and what impact will temperature change have on growth rates?
- How can we evaluate not only "who eats who" in marine ecosystems, but also determine what physical, chemical and biological forcing factors influence distributional patterns and boundaries ("why eat here and not there”)?
- How can coastal communities best respond to changing spatial and temporal patterns in the availability of subsistence species associated with changes in pelagic-benthic coupling?

Recommended Future Direction #4: Determine standing stocks, secondary production and food web structure of marine ecosystems in a local to regional context

Major findings: PacMARS data aggregations have documented biological patterns of composition, abundance and biomass of larger biotic components on a regional scale that are consistent with expected current patterns and other forcing functions. This is true for benthic fauna (>1mm), mesozooplankton, and fish. However, poor data coverage remains in many nearshore areas. Synthesis results documented spatially and temporally persistent patches of high benthic biomass in contrast to large spatial and temporal variations in zooplankton standing stock. There is an overwhelming dominance of invertebrates in both diversity and standing stock over fishes. Copepod crustaceans dominate zooplankton diversity, abundance and biomass, whereas mollusks, polychaetes, crustaceans, and echinoderms dominate benthic diversity, abundance and/or biomass. Spatial distribution of marine mammals and seabirds has also improved considerably over the past decade, using visual observations and instrumental tracking methods, although understanding seasonal patterns remains a major limiting factor.

Data gaps: Gaps in biomass inventories still exist for: (1) biota missed by traditional sampling gear including krill (an important prey for bowhead whales) and deep-dwelling bivalves (an important prey for walrus), and (2) for small but likely important organisms in the food web (e.g., microzooplankton and meiobenthos). For most fauna or communities, however, data are lacking on their population dynamics, (i.e. consumption, secondary production, growth and mortality). Such data are required in order to model carbon flows, trophic efficiencies and understand time scales at which biomass is being produced. Such information will enable us to assess ecosystem resilience to changes or stressors. Understanding also is needed of the current role of different food source end members in Pacific Arctic food webs to evaluate the potential future roles of marine and terrestrial carbon sources under changing productivity, runoff and coastal erosion regimes. Future research planning should encourage the continuation and technological improvements to telemetry programs for marine mammals, fishes, and seabirds, as well as integrating passive acoustics program more effectively into oceanographic field programs. Marine mammal vocalization data from passive acoustic arrays and animal distribution and behavioral data from satellite-linked tags help describe how, when, and why areas of preferential use are related to physical oceanographic features and phenomena. Common to this and most of the above themes is a lack of sufficient data at appropriate spatial and temporal scales to address all of the research questions identified here.

Relevance to Local Communities: Biomass rich, productive and efficient food webs are intrinsic to maintaining the success of subsistence harvests. Due to the place-based nature of community harvests and limited geographic reach of traditional hunting, local-level assessments with sufficiently high resolution are as important as regional synoptic assessments. Shifting spatial distributions of subsistence species and/or changing composition of harvestable fauna will require adaptive operational strategies and have cultural implications to local communities.

Potential Questions for Future Research:

- What is the proportional role of the primary food source end members, including potentially overlooked benthic microalgae (phytomicrobenthos) and terrestrial sources as a carbon subsidy for benthic food webs?
- What physical-biological mechanisms maintain persistent areas or “hotspots” of dense prey and concentrated feeding activity for upper trophic levels?
- What are the secondary production levels and productivity rates of the ecosystem? These rates are unexplored in contrast to those for primary production. Studies are needed to determine the growth, reproduction and mortality rates of important taxa/communities, both benthic and pelagic.

- Which sentinel organisms can be best utilized to track environmental change? Are we missing key zooplankton species (e.g., euphausiids, gelatinous organisms) in our understanding of trophic systems?
- Are there predictive relationships between biodiversity and productivity?
- What are the abundance, biomass and trophic roles of small organisms (e.g., microbes, microzooplankton, benthic meiofauna) in the carbon cycle? Currently there is limited taxonomic resolution in many of these smaller sized organism classes, even while recognizing that they will respond rapidly to temperature change than larger organisms.
- What is the role of heterotrophic bacteria in biogeochemical cycling of carbon in nearshore and offshore systems? Transfer rate data are needed for the microbial loop so it can be utilized in biogeochemical models.
- What role does gelatinous zooplankton play in Arctic ecosystems? These fragile organisms can dominate the zooplankton biomass and during blooms can potentially be detrimental to fish stocks by disrupting food webs and increasing competition through intense grazing pressure on zooplankton and ichthyoplankton.
- What are the key rate processes impacting ecosystem function and how will they respond to change? Experimental rate processes are essential for these studies.

Recommended Research Direction #5: Evaluate the chemical contaminant loads in sediment and biota for comparison to past studies and as a baseline for future monitoring of anthropogenic impacts of resource development

Major findings: A large data base for trace metals and polycyclic aromatic hydrocarbons (PAH) in surface sediments (with good QA/QC) shows essentially pristine sediments throughout the Chukchi and Beaufort seas. Some sediments within very small areas (<200 m around historic exploratory oil drilling sites, 6 of 35 studied to date) contain elevated concentrations of barium, chromium, copper, lead, mercury and polycyclic aromatic hydrocarbons (PAH) that can be linked to discharged drilling muds and cuttings. Sediment cores show no discernible metal or PAH contamination, even within the past 50-100 hundred years, except for the immediate, but extremely small areas near past drilling sites. Time series data (1986-2006) with good QA/QC are available for metals and PAH in benthic organisms (amphipods and clams) from the coastal Beaufort Sea for 1986-2006 and show low concentrations no significant temporal or spatial trends.

Data gaps: Little or no data for chlorinated hydrocarbons (e.g., PCBs, pesticides) exist for sediments from the Chukchi and Beaufort seas. Limited data for metals and no data for PAH or other organic contaminants are available for water samples from the PacMARS area. Very few data are available to trace biomagnification of relevant chemicals (e.g., methylmercury, chlorinated hydrocarbons) in benthic food webs and in higher trophic levels. Data and models are required to determine how chemical contaminants in sediments and seawater move through the food chain, especially to upper trophic levels, including humans. A better understanding is needed of migration routes and important feeding regions for marine mammals, fishes, and seabirds and how these regions will change with anthropogenic impacts (e.g., climate change, industrial development, increased shipping).

Relevance to Local Communities: Community hub meetings and literature review confirms concerns about contaminant levels in marine resources and the resulting food security and public health issues were strong and pervasive in coastal communities throughout the PacMARS study area. Even where concerns were unlikely to be linked to significant actual hazards, the paucity of available data and often ineffective communication of results to coastal communities facilitates speculation at the community level regarding food security and public health issues. Future research programs that involve chemical contaminants should incorporate local community observations, participation, and effective/relevant outreach and education of project results. Effective/relevant outreach and education includes the need for agencies and other researchers to consider their research in the context of human health and food safety and to provide results that are understandable, relevant, and meaningful to coastal community stakeholders.

Questions for Future Research:

- Will levels of chemical contaminants in sediments and seawater increase following new oil and gas development and shipping traffic changes and how will these anthropogenic chemicals move through the food chain?
- Where will the migration and important feeding regions for marine mammals, invertebrates, fishes, and seabirds coincide with comparatively higher anthropogenic inputs of chemical contaminants (originating through climate change, industrial development, increased industrial maritime transportation)?
- Are these chemicals that are biomagnified in upper trophic levels also taken up by benthic organisms and/or are they being buried in marine sediments?
- Which chemical contaminants are present in marine resources that local communities consume?
- Which, if any, of these chemical contaminants pose a significant public health hazard for human consumers and/or a significant hazard to marine resources utilized by subsistence users?

Recommended Research Direction #6: Determine the impact of changing environmental conditions and food web dynamics on subsistence lifestyles in times of climate change

Major findings: Hub meetings and interactions of PacMARS investigators with local residents over the past decades have shown that all themes considered during the PacMARS effort are relevant for local residents and thus we have integrated a 'relevance to local communities' section into every theme above. Local traditional knowledge is being increasingly appreciated in western scientific efforts and each step, even those here, provides some progress towards bridging gaps between cultures and approaches. The nearshore coastal zone is very important for the subsistence harvest of marine resources by coastal communities, and is a critical migration pathway for marine mammals and seabirds, yet it is understudied because it is inaccessible by deep-draft research vessels. Major gaps exist in the bio-geo-physical linkages in the inner coastal shelf regions of both the Chukchi and Beaufort seas, where local residents travel, hunt and fish. More studies are needed that further our understanding of the ecosystems of this riverine coastal domain and its connection to the interplay of forces from land and outer shelf regions. In addition, coastal communities engaged in traditional subsistence practices are the first to notice new species, wildlife population status and trends, wildlife disease, first sightings of migrants and/or novel species, pollution events, and coastal erosion.

Data gaps: There have been impacts on food gathering practices in coastal communities throughout the study area. Practical information needed to better understand these impacts includes how local communities directly and effectively adapt to the changes in the regional ecosystem; how changes in sea ice type, extent, and duration, as well as maritime ship noise and traffic, contaminants, and increased commercial fishing pressure will affect the distribution and health of marine resources used for subsistence. Additionally, it is unclear how the potentially negative environmental impacts described above will affect the accessibility and availability of marine resources essential to coastal communities for human consumption. More information in required on disease vectors affecting marine resources utilized by coastal communities and related human food security and public health issues. Other concerns include the impacts of offshore resource extraction including oil drilling as well as offshore, nearshore, and onshore mining activities; impacts on marine animals that are utilized by humans, in particular those with migration routes that may be affected by industrial maritime vessel traffic; impacts of warmer seawater and air temperatures on sea ice and coastal erosion, as well as the erosion/integrity of critical infrastructure (i.e. roads, buildings, ice cellars); changes in ocean current patterns and ocean fronts, and wave regimes; and the need for education and research on effective exchange and integration of knowledge and results between the research science community and local residents.

Relevance to Local Communities: Throughout the PacMARS study areas, access to key species essential for coastal subsistence harvests has become more challenging. Increased distance and related fuel costs, safety in traveling and overcoming dynamic sea ice conditions are challenges for current-day food gathering. The changing ecosystem has led to increased risks, decreased accessibility to hunted foods, and less economic stability, as well as human health, and food security concerns in communities from the northern Bering Sea to the Beaufort Sea. Additional threats include ship strikes to subsistence hunters in small boats and marine mammals, pollution events, invasive species, sub-arctic species range extensions, the introduction of novel diseases, and coastal erosion that impacts accessibility and community sustainability.

Questions for Future Research:

- What changes in predator-prey relationships have contributed to food security concerns of coastal communities?
- How can we develop better subsistence-based understanding of food webs in science models?
- What are the best methods to record and integrate local knowledge with western science approaches?
- How can we sustain documentation of the maritime subsistence use areas for the communities within the PacMARS region, especially in the coastal zone?
- How can local coastal ecosystem knowledge better inform decision-making following the consequences of coastal erosion, e.g. how will community relocation impact other components of the ecosystem?
- What strategies are being employed by coastal communities to access essential subsistence marine resources in the context of changing ice conditions?
- How can we best prepare food security vulnerability assessments connected with the health and availability of subsistence foods that incorporate challenges such as invasive species introduction/range extensions, unusual mortality events, catastrophic accidents, and chronic pollution?
- How can we use traditional knowledge to better guide the design and placement of field research in local and coastal waters?

D4. Methodological Needs for Future Research Activities

The research gaps and recommended future directions summarized in the previous section require a wide array of approaches, methods, and tools that we do not fully list here, although some are mentioned later in this chapter. Because much Arctic ecosystem research currently is conducted under the broad framework of understanding the ecosystem in the context of climate change, here we stress the roles of long-term monitoring and synthetic analyses of time series data including past data collections where available. Also, we stress the need for, and usefulness of, integrating interdisciplinary results into (predictive) modeling of changing ocean conditions to evaluate responses by marine biota, human life styles and industrial activities. Finally, a robust data management strategy is needed to guide data collection, processing and archival activities for each of the research directions.

Relevant to the above broad-scale themes, identification of time-series trends in arctic ecosystems is one of the critical current needs that are only in an early stage of development. In order to bring credible change detection to ecosystem analysis, more standard data collection methodologies are needed, including consistency of gear type and mesh size. A suite of standardized sampling tools needs to be agreed upon and coordinated among participating scientists to compare among datasets. With rapidly evolving observing technologies and attendant accumulation of large volumes of data, consensus on collection sites, variables, data and metadata standards are important. We outline here two linked objectives that can provide methodologies for addressing some of the science needs specified in the prior section and then conclude with a discussion of objectives that can be met with modeling needs and scenario development.

Methodological Need 1: Long-term (multi-decadal) monitoring of the environment at multiple locations in the Pacific Arctic, and

Methodological Need 2: Time series retrospective analyses and synthesis studies

Major advances/infrastructure: There are few multi-decadal time-series data sets available from Arctic regions. Physical oceanographic moorings are deployed in the northern Bering Sea, Bering Strait, NE Chukchi Sea, in Barrow Canyon, and in the western and eastern Beaufort Sea. The Distributed Biological Observatory (DBO) is a developing time-series detection array composed of latitudinal transects and moorings being occupied by an international network for physical and biological measurements, but this program provides only limited benefits for process-oriented studies in the region. There are also no consistent time-series measurements in the nearshore coastal zone, a critical region for land-marine interactions and social connectivity.

Data gaps: There are critical needs for long-term studies that can lead to interpreting year-to-year variability in the coastal system, including a more extensive network of tidal gauges for sea level determinations and infrastructure that would facilitate resolution of long-period climate signals. There are only limited biochemical sensor capabilities currently available on moorings in the Pacific Arctic region. There are no equivalents in the Pacific Arctic to the LTER (Long-term Ecological Research) sites in the Antarctic or other marine and terrestrial systems where process studies are repeated seasonally and interannually. A lack of spatial and temporal coverage at the systems-level means that areas of high productivity dynamics, some producing interannually persistent “hotspots” of productivity, are poorly documented, and thus the key forcing factors are not evaluated at the appropriate scales. Other data needs include comprehensive daily/annual measurements of water column light profiles, biological processes and rates, studies of wintertime distributions and physiological states of phytoplankton and zooplankton as well as the processes controlling overwintering success and survival, and controlled laboratory studies of key organisms that provide data on growth and development as a function of temperature. These data all will facilitate appropriate parameterization of models, including determination of biogeochemical transfer processes to and from the sea ice or sea surface through the water column to the seafloor.

Methodological Need 1 for Long-term Monitoring:

- Sustain concurrent monitoring at multiple key locations for measurement of important physical, chemical and biological oceanographic variables.
- Incorporate periodic measurements of key biological rate processes into monitoring programs that better documents the causes of ecosystem resilience or response to change.
- Community-based and researcher-community collaborative efforts to undertake physical, chemical, and biological measurements that integrate local traditional-based understanding of environmental parameters with modern scientific methodologies.
- A systematic documentation of industrial maritime vessel noise impacts, integrating local knowledge and marine science perspectives is needed.
- The use of community-based, subsistence vessel fleets and smaller commercial boats in the nearshore coastal zone are recommended to provide a means of cooperation between coastal communities and scientists.

Methodological Need 2 for Retrospective Analyses:

- Interdisciplinary studies that integrate current and historical biological and social data into ecosystem models that will facilitate predictions.
- Identify the processes that facilitate persistence of biomass at specific areas of high biological productivity on an interannual basis.
- Determine how smaller components of the trophic system (e.g., meiofauna, microzooplankton, microbes) respond to climate change. For example, will these smaller organisms become more important in transferring organic carbon within the ecosystem?

Methodological Need 3: Modeling and future scenarios

Major advances versus data gaps: Recent physical and biochemical modeling is facilitating evaluation of current and future impacts of changing atmospheric, water mass and current flow and biochemical processes in the Pacific Arctic (e.g. Clement et al. 2014, Deal et al. 2014, Maslowski et al. 2014, Overland et al. 2014, Williams et al. 2014). However, only a few modeling efforts couple trophic-level biological responses to standing stock network analyses (e.g. Whitehouse et al. 2014). We conclude that there is a need for fully coupled biophysical models at process scales linking trophic dynamics to ecosystem-level responses.

Methodological Need 3 for Future Research Activities

- Identify and inform future scenarios of ecosystem response using modeling approaches and data assimilation from a wide range of measurements (including biological and biogeochemical observations).
- Use ecological network modeling to identify key mechanistic ecosystem parameters.
- Create better-parameterized models to simulate and predict present ecosystem and future ecosystem function, including during the winter.
- Lack of information on growth and development rates of key species is a gap that must be filled to enable adequate parameterization for modeling and scenario development.
- Laboratory studies of low temperature growth and development rates as a function of temperature and food supply are needed to better parameterize models; many of these rates are now taken from warm-water studies of related species.
- Create physical-biogeochemical-biological coupled models for forecasting capabilities and scenario testing.
-

Methodological Need 4: Development and Implementation of a Comprehensive Data Management Strategy

We also point out that for any of the recommended research to be successful, it is important to develop and implement a robust data management strategy to help guide the data collection, processing and archival activities implied in each of the research directions outlined above. Consideration of a project data policy and data management support strategy that ensures continuity and consistency in data formats, collection protocols, long-term stewardship and access to the rich data legacy coming from these research activities is essential. The PacMARS PI Team spent extensive time gathering disparate data, unifying the data formats and building synthesis datasets (Appendix G4) that were key to providing the comprehensive analysis described in the full report. A similar effort will be required in the future. The research community can make that job much easier and more efficient if attention is paid to data management best practices in advance of any major data collection effort. This includes development of a detailed and accurate metadata profile for each dataset and the provision of clear documentation that accurate data collection and processing procedures.

D5. Conceptual Model and Organizing Principles for an Interdisciplinary Research Effort

We developed a conceptual model for the nearshore and offshore regions of the Chukchi and Beaufort Seas to compare and contrast similar and more distinctive processes that can be used as an ecosystem starting point for evaluation (Fig. D1). Processes relating to advection of water, heat and sea ice cover and loss organize the conceptual model, and are likely important driving forces for future studies in this region (section D1**)**. The conceptual model represents parts of the Pacific Arctic shelves as distinct areas, where varying inflow and advective characteristics have an influence upon, and interact in, a bi-directional manner with adjoining slopes, the nearshore region, and/or lagoons.

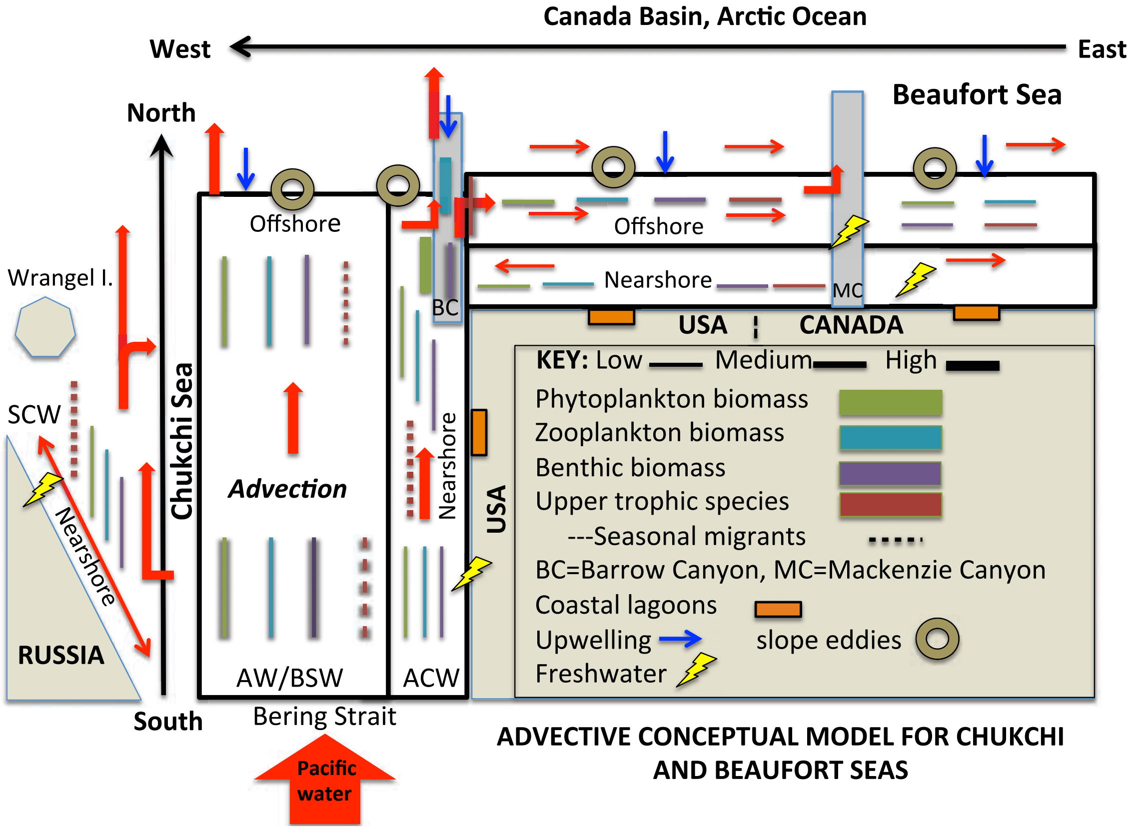


Figure D1. Advective conceptual model for the Chukchi and Beaufort seas in the Pacific Arctic region. The Pacific water advected northward through Bering Strait (large red arrow) includes all physical, chemical and biological components from the northern Bering Sea as an "input function" to this model. AW/BSW=Anadyr Water/Bering Shelf Water; ACW=Alaska Coastal Water; and SCW=Siberian Coastal Water. The model has an offshore and nearshore component; the latter considered being <20 nautical miles from the Alaskan, Canadian and Russian coasts. The smaller red arrows indicate the advection of Pacific water in the downstream portions of the ecosystem. Other components of the model are identified in the "key" within the figure and explained further in the text below.

Based on our summary of the known gaps, we propose an interdisciplinary research program that will evolve around three core topics, listed here without priority:

(1) Impacts and connectivity of advective physical forcing and changing ice cover on ecosystem structure
(2) Phenology shifts as tipping points for ecosystem functionality, and
(3) Dynamics within the nearshore zone.

The conceptual model (Fig. D1) considers the physical, chemical and biological processes in the northern Bering Sea that influence the ecosystem, with the northward advection of Pacific water being the dominant process directly influencing the persistence of high productivity in the southern Chukchi Sea. We consider the processes influencing this Pacific water mass and its components to be the "input function" to the Chukchi Sea through Bering Strait. Processes in the water column and sediment occurring in the southern Chukchi Sea have a direct impact on downstream productivity in the NE and western Chukchi Sea. The northeast Chukchi Sea is a more heterogeneous system compared to the southern Chukchi Sea, with the southern sector having more distinct water masses, and with earlier sea ice retreat and later sea ice formation. We have fewer data sets in the western Chukchi Sea in Russian waters, but studies through the RUSALCA program indicate the connectivity of upstream Anadyr and Bering Shelf waters to regions of relatively high biomass in the western Chukchi Sea. Any evaluation of the Chukchi Sea ecosystem must consider the additive influence of upstream production in the northern Bering and southern Chukchi Seas to downstream regions of both the northern Chukchi Sea and eastward into the Beaufort Sea as well as flow connections into the western Chukchi Sea, and even into the East Siberian Sea. The conceptual model conveys the implications of the more dominant advective forcing in the Bering Strait region versus the more complex biogeochemical and physical recycling in the NE Chukchi Sea with its banks and troughs, complex circulation, and the last remnants of sea ice in late summer. The fewer studies in the western Chukchi Sea limit our understanding of the system, although it is also under advective control through Bering Strait as well as eastward variable current flow from the East Siberian Sea.

Based on detailed data available, we know that nutrient-rich Pacific water transits northward through Bering Strait across the Chukchi Sea shelf and a portion of it continues eastward into the Beaufort Sea ecosystem. The surface currents in the nearshore (Alaskan) Beaufort Sea are variable as they are related to regional wind patterns, but move westward on average in the summer, with offshore surface flow to the east (see Figure D1). There is also nutrient upwelling along both the Chukchi and Beaufort Sea slope that can facilitate shelf-basin exchange of nutrients and particulate and dissolved organic carbon. Runoff influences hydrographic and ecosystem structure in the nearshore regions of both seas, but is more dominant in the Beaufort Sea. Within the freshwater-influenced coastal domain in the nearshore zone, lagoons stand out as relatively productive, yet highly dynamic areas, where climate warming could have impacts in shallow waters. Differences between the narrow Alaskan Beaufort shelf and wider shelf systems further east in the Canadian Beaufort also impact the interplay among lagoons, freshwater outflow, and nearshore productivity. Eddies produced on the outer shelf/slope regions in both seas can be an important mechanism for on- and off-shelf transport of chemical and biological products. Based on the PacMARS synthesis activities and our current understanding of the trophic components of the Chukchi and Beaufort Seas, we used generally available biomass data for phytoplankton, zooplankton, benthic fauna and seasonal upper trophic level populations in the model focused on these two seas only. This conceptual model is also primarily based on our understanding of Pacific Arctic ecosystems during the summer. There remain critical temporal data gaps related to seasonality. Posing practical hypotheses regarding timing of ice retreat and phenology requires that more data be available for the spring and fall periods. Spatial and temporal scale complexities need to be incorporated into future efforts.

We conclude by summarizing the main topics for future productive studies in the Pacific Arctic region. We use a tabular form from recommendations within the broad-scale research themes throughout Section D. Pertinent questions relevant to environmental change and data gaps arose from the key themes and identified gaps evaluated during the course of the PacMARS study. Many of our questions could be addressed in the development of a comprehensive, system-level research program or integrated complementary programs with standardized sampling methodologies for core measurements. The broad objective would be to understand the status and trends in the changing ecosystems of the Bering Strait region, as well as the Chukchi and Beaufort seas. At the start of this chapter, Table D1 provided a broad summary of the status of knowledge of environmental, biological, and human impact/use properties of the

Pacific Arctic Region ecosystem using the summaries from the synthesis (Chapters A-C). We identified subcategories of variables, and color-coded the status of knowledge in relation to spatial coverage (regional wide), interannual time series availability of data, and availability of data over seasonal time periods. This table highlights findings and gaps of our synthesis activities as discussed previously and aims to focus upon areas of data acquisition needed to further capabilities to evaluate ecosystem status and change in this region.

Table D2 follows on this effort and is a summary of our PacMARS team recommendations, data gaps, future research needs and methods outlined in the previous section of this chapter, with the goal of

Table D2. Summary table of recommendations/gaps, research needs, and methods for a systems study in the northern Bering, Chukchi and Beaufort seas.

Recommendation/Gaps	**Research Needs**	**Methodologies**
Physics and Biogeochemistry		
Seasonality of upwelling, eddy formation, advection and associated planktonic and benthic responses with linkages to nutrient cycling	New technology for continuous winter measurements, gliders, including biochemical sensors to establish phenological changes	Time-series mooring arrays, seasonal field sampling, gliders; biochemical sensor development on moorings and other platforms; gliders
Coastal erosion	Carbon and nutrient budgets, relocation of coastal communities, storm surges	Tide gauges/sea level recorders; nutrient and carbon measurements, including process studies
Shallow Beaufort Sea oceanography	Shallow ecosystem studies	Field surveys
Biological		
Time series/long term monitoring of for abundance, biomass, distribution, diversity of biota at all trophic levels	Track change over time	Monitoring: regular field survey, remote sensing
Rate measurements: biogeochemical cycles; primary, microbial and secondary production, growth, reproduction, feeding rates in association with physical characteristics (e.g., temperature, snow/ice cover, light)	Build carbon and other elemental budgets, basis for evaluating response and adaptability to changing environment	Experiments (in situ and in lab)
Seasonality of standing stocks and rates, especially during winter, and the importance of ice vs. water column production to benthic/pelagic secondary production and life cycle timing	Assess dimension of seasonal variability (informs about pre-conditioning to long-term change); better quantification of sources and flow of energy through the ecosystem	Monitoring: Seasonal field surveys and experiments, remote sensing, develop new methods to better understand food source partitioning
Define distribution ranges of species and populations and influence of environment (e.g., advection, stratification, food availability, temperature) on those ranges	Track distribution changes over time, including invasions; Identify role of physical characteristics in determining distributions	Taxonomic, (population) genetic, metagenomic studies in association with physical parameters
Life cycles of key taxa and their interaction with the environment	Evaluate life-stage specific response to system-level change	Seasonal field surveys and experiments
Increase understanding of the ecology and distribution of understudied taxa such as microbes, microzooplankton, gelatinous zooplankton	Obtain full taxonomic inventory; determine abundance/biomass and biological rates to assess ecological importance	Morphological, genetic, metagenomic biodiversity, biological rate studies
Fill regional/spatial gaps in biota abundance, biomass, distribution	Assess range of biomass in pelagic and benthic realm	Field surveys

Table D2. Summary table of recommendations/gaps, research needs, and methods for a systems study in the northern Bering, Chukchi and Beaufort seas (cont).

Recommendation/Gaps	**Research Needs**	**Methodologies**
Human Impact		
Chemical contaminants (metal, organic, radioactive) in sediments and fauna incl. benthos, marine mammals, including seasonal cycles and time series	Effects on subsistence species and harvests, food security, effects on public health	Concentrations, effects, bio-magnification, bio-accumulation through tie to stable isotope-based food web
Noise impacts, ship traffic, industrial development	Effects on subsistence species and harvests, food security, public health, social health	Acoustics, harvest success, tagging studies, coastal monitoring, social science-based studies
Climate change impacts on human infrastructure (e.g., via coastal erosion), effects of changing ice conditions on travel, hunting success, seasonal movement and location of subsistence species; alterations in productivity of subsistence species via changes in timing and magnitude of growth of lower trophic prey	Assessment of impacts on subsistence lifestyle by industrial development, sea ice retreat, and coastal erosion on coastal community lifestyle, daily activities, and food consumption; develop better subsistence-based understanding of local food webs	Local knowledge, engineering studies, remote sensing, monitoring, hotspot and integrated ecosystem studies
Oil spill response and preparedness	Impact assessment of oil and gas development	Clean-up strategy, storm surge model, concentrations, bio-accumulation, community participation/training
Ecosystem-Level Integration		
Advective connectivity: regional (Northern Bering, Bering Strait, Chukchi, Beaufort, Arctic Basins), bio-environmental	Connect down-stream to up-stream conditions, processes, changes	Interdisciplinary synthesis using well-documented data archives
Capacity to adapt to change: from physiological tolerance windows to human communities	What will a future Pacific Arctic Region look like in terms of environmental conditions and biotic responses	Physiological experiments, combine species distribution ranges with ocean temperature, community-based science and local knowledge, agency planning for subsistence harvests of "new" or currently under-utilized species
Carbon budget (including neglected microbial loop)	Identify and monitor hot spots in carbon production and remineralization	Integrate data from archives into model
Climate change consequences and predictions	Predict changes in bloom / production phenology as driven by environmental forcing, pelagic-benthic coupling, etc.	Modeling (incl. coupled ecosystem-biochemical-physical-sea ice models, regionally downscaled CGM), community-based science (incl. local knowledge, locally-driven field work)
Ecosystem functioning: integrate biotic abundance, physiological requirements, trophic connections	Understand dominant ecosystem drivers and mechanisms	Network analysis; use well-documented data archives
Assess ecosystem robustness and resilience	How resilient is the Arctic marine system to physical change	Species body size 'lump analysis'

enabling development of a systems-level study in the Bering Strait region, Chukchi Sea and Beaufort Sea. These findings can be coupled with the Chukchi Sea/Beaufort Sea conceptual model outlined here (Fig. D1) as a basis for future development of an ecosystem-level, interdisciplinary and coupled study of the Chukchi and Beaufort Sea, based upon advective forcing from the upstream Bering Strait region.

D6. Concluding Summary

The goal of the Pacific Marine Arctic Regional Synthesis (PacMARS) effort was to facilitate new and cross-disciplinary synergies in our understanding of the marine ecosystem of the northern Bering, Chukchi and Beaufort seas. The specific objectives of the PacMARS project were to: (1) identify and synthesize existing data sets that are critical for evaluating the current state of knowledge of this marine ecosystem, including human dimensions, and (2) define the high-priority, overarching scientific themes and research needs for the next decade or more of marine ecosystem studies in the Pacific Arctic Region.

The first sections of the report synthesized available data on physical, chemical and biological oceanography. We consolidated both published and unpublished data into synthesis products described in Chapters A-C. This effort included development of a composite document of available data sets and data source files (Appendix G1). The data assembled and other synthesis products have been transferred to the National Center for Atmospheric Research (NCAR)'s Earth Observing Laboratory (EOL; http://pacmars.eol.ucar.edu/) PacMARS archive and are publicly accessible.

In Chapter D we identify three overarching research themes related to our understanding of the Pacific Arctic marine ecosystem.

- Theme 1: Impacts and connectivity of advective physical forcing and changing ice cover on ecosystem structure
- Theme 2: Phenology shifts as tipping points for ecosystem functionality
- Theme 3: Dynamics within the nearshore zone

We then proceeded to identify more specific potential research directions, with associated summary of major findings within each research direction, associated data gaps, the relevancy of research directions to local communities, and potential questions to guide future research. Below are the 6 research directions identified through the PacMARS effort:

- Recommended Research Direction #1: Evaluate the impacts and connectivity of a changing ice cover and physical forcing on lower trophic production and carbon cycling

- Recommended Research Direction #2: Understand the phenology of biological production cycles in relation to the physical environment within a changing climate

- Recommended Research Direction #3: Determine the role of pelagic-benthic coupling in relation to a changing physical forcing and biogeochemical shifts

- Recommended Research Direction #4: Determine standing stocks, secondary production and food web structure of marine ecosystems in a local to regional context

- Recommended Research Direction #5: Evaluate the chemical contaminants in sediment and biota as a baseline for future monitoring of anthropogenic impacts of resource development

- Recommended Research Direction #6: Determine the impact of changing environmental conditions and food web dynamics on subsistence lifestyles in times of climate change

We point out that a broad range of approaches will be necessary to address the proposed themes. Because a high proportion of Arctic research currently is funded under the broad framework of climate change, we stress the need for long-term monitoring and synthetic analyses of time-series data including past data collections. Also, predictive modeling of changing ocean conditions is necessary to evaluate impacts of natural and anthropogenic change on marine biota, human life styles and ecosystem dynamics. The following approaches can be profitably applied in the context of the future research needs that have been identified:

- Methodological Need 1: Long-term (multi-decadal) monitoring of the environment at multiple locations in the Pacific Arctic, and
- Methodological Need 2: Time series retrospective analyses and synthesis studies
- Methodological Need 3: Modeling and future scenarios
- Methodological Need 4: Development and Implementation of a Comprehensive Data Management Strategy

We also developed a conceptual model for the PacMARS study area and summarized a tabulation of recommendations/gaps, research needs, and methods for a potential systems study in the northern Bering, Chukchi and Beaufort seas, which can be related back to the conceptual model as future research activities are developed.

The PacMARS synthesis effort evaluated existing data, including physical forcing impacts to lower trophic organisms, and was undertaken simultaneously with an independent but related effort that concentrated on an upper trophic level synthesis effort (SOAR). The approach of SOAR included a focus on preparation of peer-reviewed manuscripts that synthesized knowledge of upper trophic levels in relation to physical forcing and lower trophic connectivity. As we complete the PacMARS project, in concert with products from the SOAR effort, we expect that this joint effort with both process-level and upper trophic level syntheses, can serve as the basis for a multi-dimensional, multi-agency process to develop a coordinated, system-level, natural and social science understanding of the changing Pacific Arctic region. While it was beyond the scope of this project to meet the science management and mission needs of all and probably any individual government agency or funding entity, we recommend that the synthesis provided here be used as guidance for the development of a research program that will ultimately take full advantage of the scientific expertise, knowledge and understanding that has grown dramatically over the past several decades in the Pacific-influenced Arctic. We include within our expectations that such a research program will also take advantage of the value of local and traditional knowledge residing in local communities, and will include strategies for communication streams for stakeholders in the Pacific Arctic.

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G. APPENDICES

The following appendices provide detailed information relevant to the PacMARS report.

APPENDIX G1-PacMARS Data Source Table

This document provides an annotated list of sources for data sets considered and consulted during the PacMARS project, a listing of government organizations funding scientific collections, and a list of data archives. Our goal was to develop a comprehensive list of studies, datasets and key multidisciplinary projects in the Chukchi and Beaufort Sea region. We include expanded descriptions of data sets, links to corresponding websites, databases and points of contact. We have also included annotations on the perceived value of the accessible data to the PacMARS project. These judgments are made solely regarding the suitability of the datasets considered for the specific goals and objectives of PacMARS, and do not constitute an opinion in any other context. This document is based upon a table referred to as "Appendix A" that was included in progress reports submitted to the North Pacific Research Board and available on the PacMARS website (http://pacmars.cbl.umces.edu/). Projects/datasets are listed in alphabetical order according to acronym or long title within separate sections associated with specific themes listed below. Note that we also describe how data products are being simultaneously used during the parallel Synthesis of Arctic Research (SOAR) project within the Upper Trophics section.

Sections:

G1.1 Physical Oceanography, Chemistry and Contaminants

G1.1 a. Physical Oceanography

Beaufort Gyre Exploration Project
This Woods Hole Oceanographic Institution project is a component of the Arctic Observing Network and is described with its international partners under JWACS, the Joint Western Arctic Climate System project.

EDMIZ - Emerging Dynamics of the Marginal Ice Zone
http://www.onr.navy.mil/Science-Technology/Departments/Code-32/All-Programs/Atmosphere-Research-322/Arctic-Global-Prediction/Marginal-Ice-Zone-DRI.aspx
This is a new physical and acoustically oriented arctic research program including a sea ice emphasis that will use autonomous sampling systems. The program started in fiscal year 2012, and will work in the Beaufort Sea. Martin Jeffries at the Office of Naval Research is the key contact and a project webpage documents funded investigators and science plans at
http://www.apl.washington.edu/project/project.php?id=miz

GINA - Geographic Information Network of Alaska
http://www.gina.alaska.edu/

The Geographic Information Network of Alaska (GINA) is a University of Alaska based resource, which includes mapping tools and links to data sources. Several marine oriented projects are highlighted, including the Alaska Shorezone Mapping Project (described above under ALCC) and Seasonal Ice Zone Observing Network (SIZONET). The GINA site primarily points to other archives of data, including the one used by the North Slope Science Initiative (NSSI), see especially the North Slope Science Catalog, http://catalog.northslope.org/, which includes a comprehensive search engine for North Slope data that has been identified by the NSSI.

IMS – Institute of Marine Science (University of Alaska Fairbanks)
http://www.sfos.uaf.edu/dm/ims-data-archive/DataBase
Key contact: Steve Okkonen, okkonen@alaska.net

The Institute of Marine Science, University of Alaska Fairbanks (UAF), is the lead oceanographic research institute for this US arctic-based university. Multi-disciplinary data are available from RV Alpha Helix cruises, some Russian, Japanese and NOAA vessel cruises (presumably with UAF researchers aboard). Some data is as early as from the 1960s. Physical oceanographic data from this resource was directly used in the PacMARS synthesis efforts.

NASA PODAAC – National Space and Aeronautics Administration (NASA) Physical Oceanography, Distributed Archive Center (PODAAC)
http://podaac.jpl.nasa.gov/

NASA's Physical Oceanography Distributed Archive Center (PODAAC) is NASA's satellite oceanographic data center. Among the products available include QuikSCAT arctic sea ice imagery and animations that show the decline of multiyear ice, as well as oceanographic data, but few data products are available at this time for the PacMARS study area.

North Pacific Research Board (NPRB; http://www.nprb.org/ relevant projects:

- NPRB project #1302 "The southern Chukchi Sea's response to variations in Bering Sea circulation pathways" (http://project.nprb.org/view.jsp?id=f5879080-8ba1-4a67-a419-5b797a03535a)
- NPRB Project #1225 "Improvements to bathymetric digital elevation models spanning Alaska region waters" (http://project.nprb.org/view.jsp?id=40093f37-6464-439e-a836-c84a2998ecec)

Polar Science Center/University of Washington (PSC/UW)
http://psc.apl.washington.edu/
POC: Rebecca Woodgate <woodgate@apl.washington.edu>

The Polar Science Center includes investigators at the University of Washington conducting interdisciplinary research on the oceanography, climatology, meteorology, biology and ecology of the ice-covered regions on Earth and elsewhere in the solar system. Specifically, data from the long term Bering Strait moorings and North Pole Environmental Observatory are housed there, as well as at EOL.

SCICEX - Submarine Arctic Science Program
http://nsidc.org/scicex/data_inventory.html/

The Submarine Arctic Science Program (SCICEX) facilitated the participation of civilian scientists on research cruises about US Navy submarines during the 1990s. More recently, reductions in size of the US submarine fleet and changes in operations have reduced the capability to host civilian scientists, and all sampling efforts since 1998 have used US Navy personnel. Available data can be downloaded at the referenced webpage and additional information on the history and background on the program, as well as the advisory committee members who currently advise on sampling requests are available at http://nsidc.org/scicex/history.html and http://nsidc.org/scicex/sac.html. PacMARS PI Okkonen participated in the onboard sampling program. The results of the SCICEX program are important to understanding Arctic oceanography; for example the Study of Environmental Arctic Change (SEARCH) framework that includes the Arctic Observing Network can be traced to observations of shifts in the Pacific influenced front in the central Arctic Ocean during the 1993 USS Pargo SCICEX cruise. There are some connections with the PacMARS study area, such as the observations of high organic carbon fluxes originating from the Chukchi shelf (Guay et al. 1999; Geophys. Res. Lett., 26, 1007-1010), but sampling during SCICEX was limited to areas outside the 200-mile Exclusive Economic Zone (EEZ) of any other country, so no sampling was permitted during transits within any EEZ. As a result, we think the available data has relatively low utility for the research questions and synthesis required for PacMARS.
NRC – National Research Council http://www.nap.edu/catalog.php?record_id=13132

G1.1b. Chemistry and Contaminants

ANWAP – Arctic Nuclear Waste Assessment Program

The Arctic Nuclear Waste Assessment Program arose out of concerns in the 1990's that radioactive disposal practices in the former Soviet Union had contributed to contamination of the Arctic Ocean and its ecosystem. The program was funded through the Office of Naval Research, but unfortunately it seems to have pre-dated the systematic archiving of research data and there is no central archive. Some date are available in National Snow and Ice Data Center (http://www.nsidc.org/), particularly those collected during the 1994 Transarctic cruise of the USCGC Polar Sea and the Canadian Coast Guard Service Louis

S. Laurent, which was supported in part by ANWAP funding. In other cases, the data sets are relatively small in size and were directly presented in peer-reviewed publications. Insights about sea ice transport of contaminants and sedimentation patterns have relevance to PacMARS objectives, as do inventories of radionuclides in marine mammals harvested as food by Alaska Natives. Other significant findings of the program related to riverine contributions to the Arctic Ocean, sedimentation in the deep Arctic Ocean, the export of sea ice borne contaminants in the Transpolar Drift, and Arctic Ocean circulation inferred from tracer distributions from both Russian and western European sources. This program was loosely coordinated with other international efforts on the same topic led by other countries concerned about radionuclide contamination, including programs with participation of scientists from Korea, Norway, Japan, Russia, and the International Atomic Energy Agency. Two documents, available as .pdf files, provide general information about ANWAP, including the names of principal investigators, and references to publications from the project: http://www.tos.org/oceanography/archive/10-1_edson.pdf http://ota.fas.org/reports/9504.pdf

Habitat Assessment and Marine Chemistry
http://www.afsc.noaa.gov/ABL/Habitat/ablhab_default.php
Data sets = http://www.afsc.noaa.gov/ABL/Habitat/ablhab_datasets.htm
POC: Ed Farley Ed.Farley@noaa.gov

The Habitat Assessment and Marine Chemistry Program conducts research on chemical and ecological processes that occur in marine, tidal, and watershed habitats ranging from the Arctic to the Gulf of Alaska. This program attempts to assess bioenergetics in various species and life stages, assess the impact of development and contaminants on these species and their habitats, and map and evaluate their habitat quality. Of particular note for PacMARS is the beach seining project near Barrow, Alaska, formerly led by Scott Johnson (retired) and John Thedinga (retired); Mandy Lindeberg is the current lead for that project, the data from which will be included in the SOAR project (Appendix G2).

G1.2 Lower Trophics: Zooplankton and Benthos

(NOTE: many disciplinary data sets available within the results listed in the multidisciplinary program section of Appendix G1.6)

G1.2a. Plankton

COPEPOD – The Global Plankton Data Base
http://www.st.nmfs.noaa.gov/copepod/

"The *Coastal & Oceanic Plankton Ecology, Production & Observation Database* (COPEPOD) is an online database of plankton abundance, biomass, and composition data compiled from a global assortment of cruises, projects, and institutional holdings. COPEPOD's online zooplankton and phytoplankton data content ranges from long term ecosystem monitoring surveys to detailed process studies, each accessible via a variety of search options, and each detailed via standard visual and text-based content summaries."

NOGAP - Northern Oil and Gas Action Program
http://www.arcodiv.org/Database/Plankton_datasets.html
Zooplankton and Benthos Canadian Beaufort Sea shelf
In this program in 1986, zooplankton were collected from the Canadian Beaufort Sea shelf in May, (with ice cover), and July to September (open water). The object of the study was to assess species composition, abundance, distribution and biomass of zooplankton across the Canadian Beaufort Sea. These data are among the data sets digitized during ArcOD (see ArcOD entry above). The data archive and metadata for this project, as well as a number of other zooplankton data sets are available on the ArcOD zooplankton website (http://www.arcodiv.org/Database/Plankton_datasets.html), benthos is available at www.iobis.org (data provider ArcOD)

G1.2b. Benthos

Chirikov Basin Macrobenthos
Web address: http://www.nodc.noaa.gov/cgi-bin/OAS/prd/accession/details/8900116, http://www.arcodiv.org/Database/Benthos_datasets.html
POC: Kenneth Coyle, University of Alaska Fairbanks, (907) 474-7705

This data set includes data documenting Ampeliscid amphipod abundances in the gray whale feeding areas of the northern Bering Sea, including biomass and abundance. For select cruises, abundance and biomass for the entire infaunal community is available (ArcOD link). These are data sourced from two National Science Foundation projects funded to the University of Alaska Fairbanks in the 1980s and 2000s; a fraction of the data is being archived on the EOL website as part of PacMARS efforts. Some of these data will be used in the SOAR benthic-focused project (SOAR, Appendix G2).

North Pacific Research Board (NPRB) relevant projects:

- **NPRB #604 Norton Sound benthic fauna;**
  http://doc.nprb.org/web/06_prjs/604_Final%20report.pdf

This study used 1976-2006 bottom-trawl surveys to examine changes in distribution and biomass of dominant benthic epifauna and demersal fishes in Norton Sound. The project determined that species composition did not change over time. However, trawl catch grew significantly, driven by an increase in biomass of primarily one sea star species. The variability in biomass for each species sampled was compared to environmental parameters and indices. Several significant correlations were identified for variables in Norton Sound (east-west wind component, incident solar radiation, and the annual duration of ice-free waters), as well as one large-scale climate index (the Pacific-North American Index). Despite this, it is clear that over this time period, biological response to climate was complex and there is no simple predictive model for both water column fish and epibenthos.

- NPRB Project #1227 “Benthic lower trophic level food webs in the Chukchi and Beaufort Seas – baselines and relevance of sea ice algal production” (http://project.nprb.org/view.jsp?id=8268ddb0-6985-4dcf-9c8c-1a2c9532d19d)

- NPRB Project #1303 “Assessing benthic meiofaunal community structure in the Alaskan Arctic: A high-throughput DNA sequencing approach” (http://project.nprb.org/view.jsp?id=0a95ba00-1dee-4505-ae63-d8274892dfbb)

G1.3 Upper Trophics: Marine Mammals, Seabirds, and Fish

G1.3a. Marine Mammals

ASAMM - Aerial Surveys of Arctic Marine Mammals, funded by NOAA and BOEM
http://www.afsc.noaa.gov/NMML/cetacean/bwasp/index.php
POC: Megan Ferguson, megan.ferguson@noaa.gov

The Aerial Surveys of Arctic Marine Mammals (ASAMM) project is a continuation of the Bowhead Whale Aerial Survey Project **(**BWASP**)** and Chukchi Offshore Monitoring in Drilling Area **(**COMIDA**)** marine mammal aerial survey projects. Inter-agency agreements have been established for support of this activity between the Bureau of Ocean Energy Management (BOEM), Department of Interior and the National Marine Mammal Laboratory (NMML), Alaska Fisheries Science Center, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, Department of Commerce. The goal of these studies is to document the distribution and relative abundance of bowhead, gray, right, and fin whales, belugas, and other marine mammals in areas of potential oil and natural gas exploration, development, and production activities in the Alaskan Beaufort and northeastern Chukchi Seas. There are links to information on aerial surveys of marine mammals at this site over a 30+ year period. Megan Ferguson is the NMML contact who can advise on crediting requirements and comment on technical use of the data. The data set itself is in Microsoft Access format. Information from these aerial surveys is being widely incorporated into various SOAR analyses and papers (Appendix G2), as well as the PacMARS data synthesis understanding of marine mammals distributions relative to other ecosystem variables and forcing functions. Data are available here:
http://www.afsc.noaa.gov/NMML/software/bwasp-comida.php

BWASP - Bowhead Whale Aerial Survey Project
http://www.afsc.noaa.gov/NMML/cetacean/bwasp/flights_BWASP.php)
This aerial survey project is now part of the ASAMM program, outlined above.

LGL Alaska Research Assoc. Inc./ LGL Limited
http://lgl.com/

The Alaska and Canada offices have both been active in the region for decades and have different names. There are periodic publication of reports to the National Marine Fisheries Service about the impacts of oil and gas industry activities on marine mammals. The reports are titled "Joint Monitoring Program in the Chukchi and Beaufort Seas" and are produced by LGL, Jasco Applied Sciences and Greeneridge Sciences. The reports present information about marine mammal monitoring and mitigation activities during offshore operations and effects on marine mammal impacts, distribution and behavior. These reports are submitted in compliance with Incidental Harassment Authorizations issued by the National Marine Fisheries Service and report the results of marine mammal monitoring from vessels, aerial surveys and passive acoustic monitoring.

NMML - National Marine Mammal Laboratory
http://www.afsc.noaa.gov/nmml/
POC(s): John Bengtson, Director <john.bengtson@noaa.gov>; Robyn Angliss, Deputy Director robyn.angliss@noaa.gov

The National Marine Mammal Laboratory (NMML) conducts research on marine mammals important to the mission of the National Marine Fisheries Service (NMFS) and the National Oceanic & Atmospheric

Administration (NOAA), with particular attention to issues related to marine mammals off the coasts of Alaska, Washington, Oregon, and California. Research conducted by NMML relies on a variety of methods and tools. Determination of status and trends of marine mammal populations requires information on abundance, stock structure, mortality and net productivity. To obtain these data, censuses are carried out from ships, aircraft and on land. Radio and satellite-linked telemetry is used to determine movements and migrations, critical feeding areas and depths, and other behavioral data. Statistical analyses and modeling are carried out to investigate specific population parameters. Research programs are carried out cooperatively with many other federal, state and private sector collaborators.
Additional details of survey protocol are provided in Clarke et al. (2013) and survey data are available from the National Marine Mammal Laboratory, National Marine Fisheries Service (http://www.afsc.noaa.gov/nmml/software/bwasp-comida.php).

North Pacific Research Board (NPRB; http://www.nprb.org/ relevant projects:

- NPRB Project #1312 "Assessment of a Genetics Based Capture-Mark-Recapture Approach for Estimation of Abundance and Demographic Rates of Pacific Walruses" (http://project.nprb.org/view.jsp?id=4470425b-99d1-4b3d-9dcc-d5e4711e09e6)

  NPRB Project #818 "**W**alrus Distributional and Foraging Response to Changing Ice and Benthic Conditions in the Chukchi Sea (http://project.nprb.org/view.jsp?id=07d2ebd6-93ac-462a-b907-ae4085c5bed5)

NSB/DWM - North Slope Borough/Department of Wildlife Management
http://www.north-slope.org/departments/wildlife/

The North Slope Borough Department of Wildlife Management (NSB/DWM) is an important player in community-invested research on the North Slope, particularly studies relating to marine mammals and waterfowl. There are several categories of research accomplished through North Slope Borough funding. For wildlife studies, refer to:http://www.north-slope.org/departments/wildlife/studiesNresearch.php; For subsistence co-management activities that are coordinated with federal and state agencies, refer to: http://www.north-slope.org/departments/wildlife/co-management.php; POC(s): Senior Scientists: Craig George craig.george@north-slope.org, Robert Suydam robert.suydam@north-slope.org

The NSB/DWM facilitates sustainable harvests and monitors populations of fish and wildlife species through research, leadership, and advocacy from local to international levels. The Department diversifies funding opportunities through the submission of grant proposals focusing on subsistence species and issues of the highest interest to North Slope residents. The DWM is responsible for helping to assure participation by Borough residents in the management of wildlife resources, by keeping these resources at healthy population levels, and to assure that residents can continue their subsistence harvest of wildlife resources. Thirty-year partnerships with state and federal agencies (see subsistence co-management activities) include studies focused on bowhead whales, belugas, ices seals, seabirds, sea ducks and nearshore marine fishes, among other. The 1978-2011 bowhead abundance data can be requested via a "data availability agreement" or through a formal request. The 'final' population estimates are all published in the peer-reviewed literature. There are other datasets on harvest numbers of bowheads that are available through the DWM or Alaska Eskimo Whaling Commission (AEWC). Data from ongoing studies on beluga whales and nearshore fisheries are also available upon request. Note that data from several of these studies, including contaminants, are being used in SOAR analyses and papers (Appendix G2). Information on a diverse array of research projects are available under the 'Studies and Research Projects' web link on the DWM website.

PWID - Pacific Walrus International Database
http://alaska.usgs.gov/science/biology/walrus/pwid/index.html

The Pacific Walrus International Database includes legacy and current data on Pacific walruses, including land and at sea ice haulout counts, harvest data from Russian sources, sex/age composition, reproduction, mortality, harvest statistics, and morphometry. and at-sea observation data. This is a controlled access database, but metadata describing the available data are readily available at the referenced website. Chad Jay, a walrus specialist from the US Geological Survey served as a PacMARS collaborator and assisted with the contributions of current satellite telemetry data for walrus distributions, as well as helping to integrate the insights available from this database into the overall understanding of walrus biology within the PacMARS study area. A SOAR benthic paper (Grebmeier et al.) will utilize walrus data in a synthesis mode.

SOAR - Synthesis of Arctic Research
http://www.arctic.noaa.gov/soar/
POC(s): Sue Moore Sue.Moore@noaa.gov, Phyllis Stabeno Phyllis.stabeno@noaa.gov

The SOAR program aims to create a platform for collaboration among scientists and Alaska Arctic residents. The SOAR has the overarching goal of using available data, analytical and modeling approaches to identify and test hypotheses that cross scientific disciplines. The geographic area is the Pacific Arctic sector, including the northern Bering, Chukchi and Beaufort seas, with time frames extending from days to decades. The aim is to develop peer-reviewed scientific papers to support understanding of relationships among oceanographic conditions, benthic organisms, lower trophic (forage fish and zooplankton) and upper trophic (seabirds, and marine mammal) species distribution and behavior in the Pacific Arctic. The SOAR project is supported by the Bureau of Ocean Energy Management (BOEM), and will assist in their evaluation of oil and gas development in the Arctic. The first phase of SOAR (2011-2014) is focused on development of 16 peer-reviewed papers for publication as a Special Issue of *Progress in Oceanography* (Appendix G2).

G1.3b. Seabirds

Divokey, George. Data from the time series research on Black Guillemots by Dr. George Divoky on Cooper Island are available at http://aknhp.uaa.alaska.edu/wp-content/uploads/2013/05/Cepphus_grylle_report.pdf for a brief synthesis/.

LGL – LGL Alaska Research Assoc. Inc/ LGL Limited
http://lgl.com/

LGL has carried out a wide variety of studies on marine and aquatic resources, many of which are related to oil and gas exploration and production along the coastal Beaufort Sea. Their studies include the following: (1) extensive ecological research on *Arctic* Cod (*Boreogadus saida*) and other fish, (2) investigation of the effects of seismic activities on whales and (3) surveys of terrestrial and marine birds.

NPPSD - North Pacific Pelagic Seabird Database
http://alaska.usgs.gov/science/biology/nppsd/index.php
POC: Gary Drew (gdrew@usgs.gov) and John Piatt (jpiatt@usgs.gov)

The NPPSD now contains more than 325,000 samples dating back to the 1970's OCSEAP surveys, detailing the distribution of marine birds at sea in the North Pacific, including data from the PacMARS area. The database now includes a large number of transects in the northern Bering and Chukchi/Beaufort seas collected largely by the FWS (K. Kuletz) as part of NPRB and BOEM funded cruises (2006-2012) and industry programs such as CSESP (Chukchi Sea Environmental Studies Program; www.fairweatherscience.com) . Many of the research publications resulting from the database are available in electronic versions. USGS has ended the current round of data assimilation (through 2012), and are working on finalizing Version 2.1 of the database, expected to be released by end of 2013. Some bird distribution maps are readily available at the referenced webpage, while the overall Microsoft Access database that is available now is distributed via a CD (Drew, G.S., and J.F. Piatt. 2012. North Pacific Pelagic Seabird Database v2.0.. Research publications resulting from the database are documented, and many of these publications are available in electronic versions. Public availability of data from this public website is limited, but data collected as part of NPRB and BOEM–funded projects are available separately via Kathy Kuletz (USFWS), a PacMARS collaborator. Currently, oceanographic context or appropriate links for the bird observations is not provided, but USGS is building a database that links bird ecology (body size, diets, energy consumption) to seabird densities at sea so we can examine spatial patterns in biodiversity, energy flow, fish consumption , etc., and relate these to biogeographic features such as bathymetry, primary production, and sea surface temperature, etc. This work will be made available to PICES and NOAA/NMFS for integrated fisheries management by January, 2014. USGS continues to receive additional sample records that will be archived until the next revision of the database. [Marine Ecology Project, contacts J. Piatt, G. Drew].

Seabirds.net
http://seabirds.net/seabirdinfonetwork.html
POC: Robert Kaler (Robert_kaler@fws.gov)

Seabirds.net is a portal for accessing global seabird databases, including the North Pacific Seabird Data Portal (NPSDP; http://axiom.seabirds.net/maps/north-pacific-seabirds) and the Circumpolar Seabird Data Portal (http://axiom.seabirds.net/circumpolar_portal.php) that are both hosted by Axiom Consulting & Design in Anchorage. The NPSDP includes interactive maps of seabird colony, population, and diet records and are potentially key resources for understanding seabird distributions. The website notes that the mapped distribution data are preliminary and subject to correction. Other website links from seabirds.net include the Global Seabird Colony Register and ebird.org, which is a crowd-sourced, on-line checklist program that includes arrival and departure dates for specific species, and abundance information. The colony location data has been used during the SOAR marine bird and mammal hotspot analysis to control for colony-effect on seabird distributions at sea. The diet information, while still a work in progress, has potential to help link seabirds with their prey throughout the region and over time.

STAMP - Seabird Tissue Archival Monitoring Program
http://www.nist.gov/mml/csd/seabirdeggs.cfm

This archival program is tracking geographic and temporal trends in contaminants in seabird eggs, including persistent bioaccumulating contaminants (e.g., chlorinated pesticides, polychlorinated biphenyls (PCBs), brominated flame retardants [polybrominated diphenyl ethers—PBDEs], butyltin compounds, and mercury). The work involves cooperation with personnel from the U.S. Fish and Wildlife Service Alaska Maritime National Wildlife Refuge and the U.S. Geological Survey Biological Resources Division, implemented by the National Institute for Science and Technology (NIST), which is storing seabird eggs from major seabird colonies such as at Cape Lisburne using standardized protocols, under conditions that ensure chemical stability during long-term (decadal) storage, and analyzing subsamples of the stored material to determine baseline levels of contaminants of interest. The seabird egg collection is maintained in NIST's Marine Environmental Specimen Bank at the Hollings Marine Laboratory in Charleston, South Carolina. This program is a contribution to the international CAFF monitoring effort.

G1.3c. Fish

ACES-Arctic Coastal Ecosystem Study
Web address: None yet
POC: Kevin Boswell, (kmboswel@fiu.edu), 305-919-4009, Johanna Vollenweider, (Johanna.Vollenweider@noaa.gov)

Funded by BOEM, this coastal study will revisit sites in the nearshore Chukchi and Beaufort Sea sampled earlier by Johnson and Thedinga (see below). Fishes will be surveyed in 2013 and 2014 including net and acoustic surveys

BASIS - Bering-Aleutian Salmon International Survey
http://www.npafc.org/new/science_basis.html;
http://www.afsc.noaa.gov/ABL/MESA/archives/mesa_occ_basis.htm

The Bering-Aleutian Salmon International Survey-II (BASIS-II) is the North Pacific Anadramous Fish Commission (NPAFC) coordinated program of cooperative research on Pacific salmon in the Bering Sea designed to clarify the mechanisms of biological response by salmon to the conditions caused by climate changes. Recent fluctuations in the abundance, survival, and growth of salmon in the Bering Sea have occurred coincidently with fluctuations in the physical and biological oceanographic conditions. The BASIS survey of the Bering Sea epipelagic ecosystem was designed to improve our understanding of salmon ecology in the Bering Sea and to clarify mechanisms linking recent changes in ocean conditions with salmon resources in the Bering Sea.

The Bering-Aleutian Salmon International Survey Phase I site is now archived and replaced by NOAA's Ecosystem Monitoring and Assessment Program (EMA, described below). The data collections reported on the archived site include that collected during epipelagic fish surveys extending into the northern Bering Sea through 2006. Other data potentially available include physical oceanography, surface nets and zooplankton, although many of the data sets are not directly available for downloading and are reported to be in progress.

Beaufort Sea Marine Fish Monitoring http://www.afsc.noaa.gov/REFM/stocks/fit/Beaufort.php
POC: Libby Logerwell, libby.logerwell@noaa.gov

This study was undertaken in 2008 and documents fish populations in the offshore Beaufort Sea. Data collected tends to confirm expectations of low fish biomass relative to epibenthic invertebrates. Several peer-reviewed publications resulted from the study and links to those papers and the cruise report are available on the referenced website, as are NOAA personnel knowledgeable about the project. Data from this project are archived in the AFSC RACE data base and with BOEM, the funding agency. Data on epifaunal invertebrates are included in the PacMARS synthesis and fish data will be incorporated in the SOAR project describing fish of the Beaufort and Chukchi seas (G3).

Beaufort Sea Marine Fish Surveys
POC: Brenda Norcross, bnorcross@alaska.edu

These surveys include: 2008 survey see project directly above (Logerwell); 2010 WWW1004, 2011 BeauFish, 2012-2014 US Transboundary (partnering with Canadian BREA, see above).

These ongoing studies focus on fish surveys of the US Beaufort Sea, but also include surveys of epibenthic fauna, zooplankton and, for some cruises, macrobenthos. The BeauFish 2011 survey covered much of the US shelf from ~20-220 m depth. The final report is in progress. The 2012-2014 Transboundary surveys focus on the Eastern Beaufort Sea and the shelf break down to 1000 m. Because these studies are very recent, they will not be fully synthesized in the PacMARS work. A presentation is available at http://seagrant.uaf.edu/conferences/2013/wakefield-arctic-ecosystems/presentations/norcross-transboundary.pdf

EMA - Ecosystem Monitoring and Assessment NOAA Marine Fishes and Oceanography
http://www.afsc.noaa.gov/ABL/EMA/EMA_Datasets.htm

The Alaska Fisheries Science Center conducts research on fish habitat and stock assessments, as well as collecting data that includes nutrients, phytoplankton, zooplankton, temperature, and conductivity (salinity) measurements. In the PacMARS study area, on-going projects include work in the Chukchi and northeast Bering Sea. Some data are available, particularly under the BASIS project, described separately above, and these data are more extensive in the Bering Sea.

The Northeastern Bering Sea EMA program http://www.afsc.noaa.gov/ABL/EMA/EMA_NEBS.php). Pelagic trawl (surface trawl and mid water acoustics) and oceanographic data collected during the Northern Bering Sea survey are used to improve understanding of the pelagic ecosystem and assist efforts aimed at reducing uncertainty in harvest management of fishery resources important to Alaskan commercial and subsistence fisheries. The survey addresses how species distribution and marine food webs are altered by climate and seasonal loss of Arctic sea ice in the Bering Sea.

The Arctic/Chukchi Sea Ecosystem Assessment EMA program in the Chukchi Sea and Arctic http://www.afsc.noaa.gov/ABL/EMA/EMA_Chukchi.php is investigating ecosystem status and trends with the continued loss of sea ice and study its effect on the distribution, migration, energetics, and survival of commercially important fish species in the Bering Sea/Chukchi Sea. Scientists within the EMA Program partnered with the University of Alaska Fairbanks, School of Fisheries and Ocean Sciences to provide a comprehensive assessment of the northeastern Bering Sea and Chukchi Sea (NEBS/CS) ecosystems including the physical environment, the primary and secondary producers that support Arctic marine food webs, and the numerous fish species utilizing the area beginning in 2012.

Recent publications from the EMA office of NOAA Marine Fishes and Oceanography are available at: http://www.afsc.noaa.gov/ABL/EMA/EMA_Publications.php and include papers relevant to the PacMARS study areas.

Endicott Fish Monitoring Program

Studies at West Dock, Badami, Pt Thomson, and others contain fish sampling, oceanographic, in some cases meteorological, and other data for the nearshore zone of the Beaufort. The OCSEAP Simpson Lagoon study (in the 80's) conducted with Federal funds developed many reports and papers. AFS published 2 symposia on offshore development that contain papers relevant to the Beaufort. MJM Research has done much work for ARCO/C-Phillips, including monitoring the subsistence fishery in the Colville Delta annually for decades - fish sampling there covers cohorts of ARCS and other amphidromous and anadromous fishes that inhabit the Beaufort seasonally but overwinter in the Colville. For further information on these reports, contact the fishery biologists with LGL, BP, ConocoPhillips, and the North Slope Borough.

LGL – LGL Alaska Research Assoc. Inc/ LGL Limited
http://lgl.com/

LGL has carried out a wide variety of studies on marine and aquatic resources, many of which are related to oil and gas exploration and production along the coastal Beaufort Sea. Their studies include the following: (1) extensive ecological research on *Arctic* Cod (*Boreogadus saida*) and other fish, (2) investigation of the effects of seismic activities on whales and (3) surveys of terrestrial and marine birds.

National Marine Fisheries Service/National Marine Mammal Lab, NOAA
http://www.afsc.noaa.gov/nmml/software/bwasp-comida.php

Fisheries survey data are available from the National Marine Mammal Laboratory, National Marine Fisheries Service

North Pacific Research Board (NPRB; http://www.nprb.org/ **relevant projects:**

- NPRB Project #1228, "Arctic cod in a warming ocean: the interactive effects of temperature and food availability" (http://project.nprb.org/view.jsp?id=6926ad2c-a556-47fa-b3ad-3be4e26426ca)

- NPRB project #1229 "Arctic coastal ecosystems: Evaluating the functional role and connectivity of lagoon and nearshore habitats" (http://project.nprb.org/view.jsp?id=e2913b18-8a8c-4aa9-8765-fbb8450d26ad)

SHELFZ- Shelf Habitat and Ecology of Fish and Zooplankton
Web address: none yet
POC: Leandra deSousa, Leandra.Sousa@north-slope.org 907-852-0350

This ongoing study will collect baseline data on the habitat, abundance, distribution and species composition of zooplankton and fishes. It will identify similarities and differences between the very nearshore and offshore areas in fish and zooplankton communities. Surveys of fishes and zooplankton will be conducted from the beach to ~55 miles offshore between Barrow and Wainright in the summer of 2013 using various pelagic and demersal nets and acoustic tools with funding from the Coastal Impact Assistance Program; http://wsfrprograms.fws.gov/Subpages/GrantPrograms/CIAP/CIAP.htm

WBSFS - Western Beaufort Sea Fisheries Study
http://www.alaska.boemre.gov/reports/2010rpts/2010_048.pdf (Contact Brenda Norcross at bnorcross@alaska.edu for access password)

G1.4 Biodiversity Programs

ArcOD – Arctic Ocean Diversity

Web address: http://www.arcdiv.org/
http://dw.sfos.uaf.edu/arcod/ and www.iobis.org
POC (general): ArcOD@sfos.uaf.edu, Russ Hopcroft (rrhopcroft@alaska.edu) and Cheryl Clark (cclarkehopcroft@alaska.edu) for data issues
POC (PacMARS): Bodil Bluhm (babluhm@alaska.edu), Carin Ashjian (cashjian@whoi.edu), Kenneth Dunton (ken.dunton@mail.utexas.edu)

Arctic Ocean Biodiversity was a component of the Census of Marine Life program, and aimed to document the diversity in sea ice, the water column and sea floor, including fish, mammals & birds. This program was greatly successful in consolidating what is known and filling remaining knowledge gaps. Much of this work was accomplished during the International Polar Year although the effort extended over a decade with support from the Sloan Foundation. PacMARS investigators were directly involved in ArcOD and knowledge and experience from this project are directly reflected in the PacMARS effort. Data are accessible at www.iobis.org (chose 'search data', 'datasets', sort by provider name, and >60 data sets will show under 'ArcOD/AOOS') and www.arcodiv.org in Darwin Core format, the standard for biodiversity data. Several historic data sets were rescued and made available electronically, for example extensive zooplankton data from the Canadian Beaufort Sea collected in the 1980s (see NOGAP further down). Other examples include zooplankton collections from the US Fish and Wildlife Service vessel Tiglax, which are documented at http://www.arcodiv.org/Database/Plankton_datasets.html and benthic data from Russian collections at http://www.arcodiv.org/Database/Benthos_datasets.html. of the data compiled and more than available online was synthesized in a special issue in Marine Biodiversity 41(1) in 2011.

Arctic Biodiversity Assessment
http://www.caff.is/aba

The Arctic Biodiversity Assessment was released at the May 2013 Arctic Council meeting in Kiruna, Sweden and it provides information on status and trends in arctic biodiversity. A PacMARS investigator, Bodil Bluhm, was involved in writing two chapters in this high-level report, so information on expansion of species distributions in the Pacific Arctic, the influence of climate change, and the loss of sympagic fauna as seasonal sea ice declines are all topics that are incorporated into the PacMARS evaluation of research topics of importance in the Pacific-influenced Arctic. Other information resources in the report

CAFF – Conservation of Arctic Flora and Fauna
Web address: http://www.caff.is/
POC (general): CAFF Secretariat, caff@caff.is, +354-462-3350
POC (PacMARS): Bodil Bluhm (bodil.bluhm@uit.no)

The Conservation of Arctic Flora and Fauna secretariat is the biodiversity working group of the Arctic Council. Representatives of the working group are appointed by member states of the Arctic Council, and observer countries, organizations, and indigenous people organization. The secretariat supports a range of strategies that provide scientific and conservation recommendations for protecting diversity and directly conserving individual species. These strategies form a framework to ensure more effective management responses. These strategies are developed via international cooperation among countries and scientists across the Arctic. Specific CAFF programs that may be of importance to the PacMARS effort include:

(i) ABA- Arctic Biodiversity Assessment
Web address: http://www.caff.is/aba

The Arctic Biodiversity Assessment (ABA) is a major circumpolar effort to provide a description of the current state of Arctic biodiversity and it includes a full scientific assessment, released in May 2013. It is also accompanied by a suite of policy recommendations for consideration by the Arctic Council. Three versions of the report can be downloaded (recommendations for policy makers, a synthesis, and the full science report): http://www.arcticbiodiversity.is./index.php/the-report/. The full scientific assessment is a go-to, more than 500 page source for some of the best current information on the status of key ecosystem organisms, including marine mammals and migratory birds, as well as biological hotspots, human languages, and myriad other biodiversity topics. While the approach is exhaustively pan-arctic, much valuable information on the integration of the PacMARS study area within the larger Arctic is possible because of this analysis.

(ii) Circumpolar Biodiversity Monitoring Project (CBMP)

http://www.caff.is/index.php?option=com_content&view=article&id=387&Itemid=1187
http://www.caff.is/index.php?option=com_content&view=article&id=499&Itemid=1014
(marine ecosystem monitoring)
http://www.caff.is/images/marine_plan_Lowres_final.pdf
POC (general): Mark Marissink (Mark.Marissink@naturvardsverket.se)
POC (PacMARS): Bodil Bluhm (bodil.bluhm@uit.no)

The Circumpolar Biodiversity Monitoring Program (CBMP) is an international network of scientists, governments, indigenous organizations and non-governmental groups working to effectively monitor the Arctic's living resources. The CBMP organizes its efforts around the major ecosystems of the Arctic, coordinating marine, freshwater, terrestrial and coastal monitoring activities while establishing international linkages to global biodiversity initiatives. The CBMP emphasizes data management, capacity building, reporting, coordination and integration of Arctic monitoring, and communications, education and outreach. The marine ecosystem monitoring component is most relevant to PacMARS; the referenced marine ecosystem monitoring website includes science planning and general assessment documents, workshop and meeting reports. Information derived from CBMP has been primarily used in the PacMARS effort as background information for the biologically-oriented portions of our effort, particularly biodiversity.

(iii) CAFF/Arctic Council as part of the Circumpolar Seabird Expert Group
http://www.caff.is/expert-group-documents/view_category/16-circumpolar-seabird-expert-group-cbird

The Seabird Expert Group provides reports on selected seabird indicator species (Arcitc Biodiversity Series, 2010), monitoring needs (Petersen et al. 2008), seabird harvest (Merkel and Barry 2008), and meeting summaries.

G1.5 Human and Social Sciences

AEWC – Alaska Eskimo Whaling Commission
Web address: http://www.bluediamondwebs.biz/Alaska-aewc-com/default2.asp
POC (general): Alaska Eskimo Whaling Commission, P.O. Box 570, Barrow, Alaska 99723, 907-852-2392

The Alaska Eskimo Whaling Commission (AEWC) is a co-management entity that serves the interests of bowhead whalers in ten villages extending from Saint Lawrence Island to Kaktovik. The major objectives are to safeguard the bowhead whale and its habitat and to support the whaling activities and culture of its member communities. The AEWC plays an important role in influencing research priorities for bowhead whales and related ecosystem questions, and the individual village commissioners who serve hold significant reserves of traditional ecological knowledge. Nevertheless the organization does not directly collect or distribute research data; also see NSB/DWM.

Alaska Community Action on Toxins
http://www.akaction.org/Tackling_Toxics/Food/Traditional_Foods.html

This organization advocates for Alaska Native concerns connected with contaminants and safety of the locally harvested food**.**

Alaska Native Knowledge Network
http://ankn.uaf.edu/index.html

The Alaska Native Knowledge Network provides resources for teachers, advises on the ethics of conducting research in local communities, and provides summaries of workshops and conferences relevant for Alaska Native Studies.

Alaska Native Tribal Health Consortium Local Environmental Observer Network
http://www.anthc.org/chs/ces/climate/leo/

This Local Environmental Observer program archives community-based observations of the new species or new environmental behavior; it includes observations from communities in the PacMARS region.

AHDR – Arctic Human Development Report
Web address: http://www.svs.is/AHDR/

The Arctic Human Development Report was a high-level social science assessment of the welfare of human communities in the Arctic that was sponsored by the Arctic Council while Iceland served as a chair of the organization in 2002-2004. Electronic copies of the report are available at the referenced website, and the report was published through the Stefansson Arctic Institute, Borgir, Nordurslod, IS-600 Akureyri, Iceland. The overall report is clearly important, but is directed at summarizing knowledge and facilitating comparisons on a circumpolar basis, rather than serving as an original source of data. References in each chapter provide original data, so the report also serves identifies important bibliographical resources.

AHHI – Arctic Human Health Initiative
Web address: http://arctichealth.nlm.nih.gov/

The Arctic Human Health website is a US government data portal that provides search functions for original research publications that relate in some way or another to human health at high latitudes. The criteria are quite broad so thar many references are to papers that are not specifically health related. Bibliographical information on more than 100,000 publications, both peer-reviewed and gray literature are included. Other features of the website are links to other web portals and websites that provide information on a wide variety of arctic topics, some quite distant from human health, so this quite a good resource to keep in mind, but finding unique data or information that is unavailable elsewhere is relatively hard to find, but it does include references to out of print publications and information from special collections held in the Alaska Medical Library at the University of Alaska Anchorage.

ALSS - Arctic Landscape Conservation Cooperative
Web address: http://arcticlcc.org/
POC (general): Greg Balogh (Greg_balogh@fws.gov)

Landscape Conservation Cooperatives are an initiative led by the US Department of the Interior, which has responsibilities for national park, and wildlife refuge management, as well as other federally owned lands and resources. The mission statement of the Arctic Landscape Conservation Cooperative (ALCC) includes goals of identifying and providing information needed to conserve natural and cultural resources in the face of landscape scale stressors, particularly climate change. It is fundamentally a multidisciplinary program, supported by a steering committee and directed by a science plan (http://arcticlcc.org/about/scienceplan/), which supports coordinated actions among management agencies, conservation organizations, communities, and other stakeholders. Not all of the projects supported by the ALCC are relevant to PacMARS since the landscape protection components are often located in watersheds and on land, but we consider the ShoreZone mapping program and the Threatened Eider Database (http://arcticlcc.org/products/spatial-data/show/threatened-eider-geodatabase-for-northern-alaska-2012-edition to be two of several significant contributions of the ALCC that are relevant to the scope of the PacMARS effort. Another component of the program is the BIOMAP Alaska project, which is using local residents of Barrow, Kotzebue and Kaktovik to collect data on local observations, and upload that information via the web. Overall, ALCC is a program that is developing so not all information is readily available, such as the identity of investigators of individual ALCC projects.

ASI - Arctic Social Indicator Project
http://www.svs.is/ASI/ASI.htm

The Arctic Social Indicator project is a follow-up to the Arctic Human Development Project (AHDP), described above. The 160-page report was published in 2010 and can be freely downloaded as a .pdf file. It is a high-level synthetic summary that provides an up-to-date summary of social indicators on a pan-Arctic basis. References to original literature are included.

BIOMap Alaska
http://arcticlcc.org/projects/human-system/biomap/

This is a web-based citizen-science project to locally collect observations in Kotzebue, Barrow and Kaktovik. It is also described above under the description for the Alaska Landscape Conservation Cooperative.

BLM - Bureau of Land Management NPR-A Subsistence Advisory Panel Documents
http://www.blm.gov/ak/st/en/res/npra_sap/npra_sap_docs.html

During our PacMARS social science analysis, the transcripts from the meetings of the Subsistence Advisory Panel for the National Petroleum Reserve of Alaska, organized by BLM, were reviewed.

Although the focus is primarily on the land-based resources, a thorough review helped us identify some concerns related to the marine environment.

BREA – Beaufort Regional Environmental Assessment
Web address: http://www.beaufortrea.ca/
POC for Fisheries portion: Jim Reist

The ongoing Beaufort Regional Environmental Assessment (BREA) is a multi-stakeholder initiative to sponsor regional environmental and socio-economic research that will make historical information available and gather new information vital to the future management of oil and gas in the Beaufort Sea. Research components cover biology including lower trophic levels to mammals and birds, sea ice, meteorology, and more, see http://www.beaufortrea.ca/research/. Field campaigns for biological surveys include the summers of 2012 and 2013. Data are not yet publicly available, but presentations on first results are available from a February 2013 workshop at http://www.beaufortrea.ca/results-forum-2012-2013/.

BSSN - Bering Sea Sub Network
http://www.bssn.net/

The Bering Sea Sub Network is a current National Science Foundation project that is involving a number of local residents of Bering Sea communities in providing community-based observations, particularly through surveys. A report documenting local knowledge survey results and other data is available at the BSSN website. This project is positioned to communicate concerns from Russian villages that are participating in the project. St. Lawrence Island and the Gulf of Anadyr is as far north as the project coverage currently extends, so some lessons learned from the southern Bering Sea may not be immediately transferable to the PacMARS study area.

Bureau of Land Management Arctic Field Office National Petroleum Reserve Subsistence Studies Database
Yamin-Pasternak is actively engaged in this effort.

CAVIAR - Community Adaptation and Vulnerability in Arctic Regions
http://www.cicero.uio.no/projects/detail.aspx?id=30170&lang=EN

This was an International Polar Year project that examined community vulnerabilities on a pan-Arctic basis. Two communities in the PacMARS study area, Kaktovik and Wainwright, were included in the initial planning for the project.

CHONe – Canadian Healthy Oceans Network
Web address: http://chone.marinebiodiversity.ca/
POC: Paul Snelgrove, CHONe Network Director, psnelgro@mun.ca, 709-864-3270

The Canadian Healthy Oceans Network is a National Science and Engineering Research Council of Canada strategic network focused on biodiversity science for the sustainability of Canada's three oceans including the Arctic. The network includes ~ 150 researchers from 14 universities across Canada, the federal Department of Fisheries and Oceans, and seven other government laboratories, to carry out thirty-five collaborative research projects in three interconnected themes.

Chukotka Native Marine Mammal Hunter Association
www.pacificwalrus.ru

This local Chukotka-based organization is monitoring haul-out locations of walruses in Russia with support from the Chukotka Branch of the Pacific Research Fisheries Center (ChukotTINRO). As sea ice retreats, it has been more common for walruses to haul out on the Chukchi coast instead of resting on sea ice, and the animals are vulnerable while on shore to human disturbance. The referenced website provides information, links to literature and Russian-language reports on this shift in walrus behavior. Also posted on the website is a final report in English that summarizes traditional knowledge of walruses and hunting, based upon extensive interviews of local walrus hunters in villages of Chukotka.

COSEE – Center for Ocean Studies Education Excellence
http://www.coseealaska.net/
The Alaska Center for Ocean Studies Education Excellence is primarily an educational outreach effort, but includes useful resources for integrating Alaska Native knowledge and other topics pertinent to PacMARS.

Cross Island Whaling Study

The BOEM-funded project *Monitoring Cross Island Whaling Activities, Beaufort Sea, Alaska 2008-2012: Final Report Incorporating ANIMIDA and cANIMIDA (2001-2007)*, by Michael Galginaitis, Applied Sociocultural Research, gathered long-term monitoring data on the fall Cross Island subsistence bowhead whale hunt. This study was designed to help BOEM assess whether OCS oil exploration and development activities at Northstar resulted in changes to hunting practices, or to hunting success at Cross Island.

ELOKA - Exchange for Local Observation and Knowledge of the Arctic
http://eloka-arctic.org/

The Exchange for Local Observation and Knowledge of the Arctic (ELOKA) is a project framework that was initiated during the International Polar Year. It facilitates the collection, preservation, exchange, and use of local observations and knowledge of the Arctic. ELOKA provides data management and user support through the National Snow and Ice Data Center, and it fosters collaboration between resident Arctic experts and non-resident researchers. The Bering Sea SubNetwork project, described elsewhere in this document, is one associated project. Another project under the ELOKA framework is the Seasonal Ice Zone Observing Network (http://nsidc.org/data/eloka031.html; SIZONet); see also: http://www.sizonet.org/. SIZONet is an unusual project that has a significant local community observation component that documents locally observed sea ice distributions near Wales and Barrow in the context of satellite-based data

EWC - Eskimo Walrus Commission
http://www.kawerak.org/servicedivisions/nrd/ewc/
POC: Vera Metcalf, Executive Director, VMetcalf@kawerak.org

The Eskimo Walrus Commission (EWC) co-manages subsistence walrus harvests and is primarily a stakeholder organization. Chartered in 1978 by Kawerak, Inc. of Nome, the Eskimo Walrus Commission (EWC) is the organization representing Alaska's coastal walrus hunting communities. Initially formed as a consortium of Native hunters, EWC is a recognized statewide entity working on resource co-management issues, specifically walrus, on behalf of Alaska Natives as it continues to be an essential cultural, natural, and subsistence resource to the Alaskan coastal Yupik and Inupiaq communities. A cooperative agreement between the Fish and Wildlife Service (FWS) and EWC was developed in 1997 to encourage subsistence hunters' participation in conserving and managing walrus stocks in coastal communities. In 1998, a Memorandum of Understanding among the EWC, the Alaska Department of Fish & Game, and the FWS was signed facilitating joint management of the Pacific Walrus Conservation

Fund. The majority of the funds for this conservation endowment comes from the sale of raw ivory by the EWC during state conferences and events.

Extractive Industries Working Group, International Arctic Social Sciences Association (IASSA)
http://www.arcticcentre.org/InEnglish/RESEARCH/Extractive_Industries_Working_Group.iw3

This working group of the IASSA is chaired from the Arctic Centre of the University of Lapland. It aspires to be a clearing house of information on extractive industries in the Arctic, including identifying data gaps and needs. Courtney Carothers, University of Alaska Fairbanks (http://www.sfos.uaf.edu/directory/faculty/carothers/) is the key working group member who is undertaking research in the PacMARS study area. This work includes projects on: 1. Climate Change and Subsistence Fisheries in Northwest Alaska, funded by the U.S. Fish and Wildlife Service. This study is documenting local observations of climate change relevant to subsistence fisheries in Noatak, Selawik, and Shungnak; 2. Subsistence Use and Knowledge of Beaufort Sea Salmon Populations, funded by the Bureau of Ocean Energy Management. This project is incorporating local observations from subsistence fisheries to generate better understanding about salmon use and distributions on the North Slope in response to apparent increases in salmon populations.

The First Alaskans Institute
http://www.firstalaskans.org/
Among the resources intended to help facilitate broad-range capacity building in Alaska Native communities are the links to ongoing and completed projects, some of which study indigenous perspectives on quality of life and subsistence.

Historical Subsistence Reports via UAF Rasmussen Library
Ethnographic monographs available in the UAF library.

ICC (ICC Alaska) - Inuit Circumpolar Council
http://www.inuitcircumpolar.com/

The Inuit Circumpolar Council (ICC) is a non-governmental stakeholder organization representing indigenous communities on a pan-Arctic basis. Part of the ICC's research program is an ongoing study of food security from the Inuit perspective and this information was used in development of the social science portion of the PacMARS synthesis. The "DRUM" newsletter, which is archived and can be accessed through a link on the ICC website, is an efficient way to stay informed on the current projects and community involvement on the regional and international levels.

Ice Seal Committee
http://www.north-slope.org/departments/wildlife-management/co-management-organizations/ice-seal-committee

An Alaska Native co-management group to manage ice seal populations.

IPCoMM - Indigenous People's Council for Marine Mammals
http://www.ipcommalaska.org/about.html

The Indigeonous People's Council for Marine Mammals includes as membership organizations many of the recognized co-management entities such as the Eskimo Walrus Commission that are also discussed elsewhere. Project documentation available at the referenced website includes policy documents, workshop summaries, and updates on such issues as Unusual Mortality Event and seal and walrus sickness. This resource is intended primarily to inform about the activities of the Indigenous People's

Council for Marine Mammals and to assist members of indigenous communities seeking to form partnerships with government agencies and other organizations

Kawerak
http://www.kawerak.org/tribalHomePages/index.html

Kawerak, Inc. is a non-profit community development corporation based in Nome. The website referenced provides useful local information on each of the villages in the Bering Strait region. Kawerak also houses the Eskimo Walrus Commission, which is discussed in a separate entry.

Moved by the State: Perspectives on Relocation and Resettlement in the Circumpolar North
http://www.alaska.edu/move

This project was the US portion of a larger international collaboration that was conceived under BOREAS, a EUROCORES Programme of the European Science Foundation (ESF). The full ESF project is a collaboration of researchers from five countries, including the US, Canada, Russia, Greenland, and Finland. The U.S. components included five individual researchers from the University of Alaska Fairbanks and the University of Maryland. MOVE was meant to addresses a major shortcoming in conceptualizing northern histories, presents and futures. While the phenomenon of state-induced population movements in the recent history of the circumpolar North is well known, this was the first comparative analysis of local and regional contexts and related impacts. “Moved by the state” refers to the commonality of having to cope with relocations and other population movements triggered by outside decisions. In analyzing a broad array of case studies (small and large, indigenous and non-indigenous communities, in free market and central command systems, ranging from the mid-20th to the early 21st century), the collaborative research project tested the extent of commonality. Demographic, political, social and cultural variables were used to track the similarities and differences, both among communities facing being moved now and those that have been moved in the past. Extensive fieldwork, combining participant observation, various interview and survey strategies, and the recording of oral and life histories, as well as demographic and economic data collection and analysis, are the methodological backbone of the project. The practical relevance of the project is exemplified by imminent community relocations due to direct and indirect effects of climate change. Research results, including links for downloading of two theses, and extensive background information are available on the referenced website. These research results are of value to the PacMARS study from the standpoint of identifying commonalities for community relocations that will be more likely as a result of shoreline dynamics changes and other climate-related shifts.

The Alaska Nanuuq Commission
http://thealaskananuuqcommission.org/

The Alaska Nanuuq Commission is a traditional knowledge and stakeholder organization that co-manages polar bear populations with the US Fish and Wildlife Service. The website includes links to publications exploring Native Alaskan relationships to polar bear natural history.

Native Village of Kotzebue
http://www.kotzebueira.org/

The referenced website includes a “Projects” tab that leads to the descriptions and mapping products connected with a series of seal tagging projects in Kotzebue Sound. These projects were carried out as community-agency partnerships and engaged local experts, who were able to combine subsistence opportunities with participation in the research.

Northwest Arctic Borough
http://www.nwabor.org/

The Northwest Arctic Borough is the regional government entity based in Kotzebue and extends over much of northwest Alaska. The borough website includes information on the communities in the Borough, and also informs on the Borough's Subsistence Mapping Program. A 2011 conference report that is available online at: http://www.nwabor.org/forms/SubsistenceMapConfReport.pdf summarizes the subsistence mapping project, which engages participation of subsistence experts from the NWAB communities and aims to provide cultural resources for education, as well as for planning associated with development.

RurAL CAP - Rural Alaska Community Action Program
http://www.ruralcap.com/

RurAL CAP, founded in 1965, is a private, nonprofit organization working to improve the quality of life for low-income Alaskans, specifically in rural areas. While not specifically a research organization, knowledge from this large organization (>1000 employees in 81 Alaskan communities) was incorporated into the social science evaluation of PacMARS efforts.

SDWG - The Arctic Council Sustainable Development Working Group
http://www.sdwg.org/

The Sustainable Development Working Group (SDWG) is an entity of the Arctic Council. A number of social science and sustainable development project reports and deliverables are available on the referenced website, and some of these documents are discussed elsewhere in this document. Although a high-level, pan-Arctic entity, PacMARS used insights from working group documents as part of its analysis.

SIKU - Sea Ice Knowledge and Use
http://gcrc.carleton.ca/siku

The Sea Ice Knowledge and Use (SIKU) Project was undertaken during the International Polar Year and documented indigenous observations with a focus on sea ice and the use of ice-covered habitats. The project website that is hosted at Carleton University is a treasure of traditional ecological knowledge from Alaska and Chukotka. Other components of the project were undertaken in Greenland and Canada. Sea ice dictionaries and other traditional knowledge that was transferred were used during the PacMARS synthesis.

SIWO - Sea Ice for Walrus Outlook
http://www.arcus.org/search/siwo

The Sea Ice for Walrus Outlook (SIWO) is an activity that started in 2010, and is primarily a resource for Alaska subsistence hunters in coastal communities in the Bering Strait region. The SIWO provides weekly reports from April through June with information on sea ice conditions in the Northern Bering Sea and southern Chukchi Sea. One of the goals is to improve sea ice forecasting at smaller scales than is usually provided through the National Weather Service by incorporating knowledge and local observations from local Bering Strait residents.

SLiCA - Survey of Living Conditions in the Arctic
http://www.arcticlivingconditions.org/

The Survey of Living Conditions in the Arctic was funded in the United States by the National Science Foundation. The overall pan-Arctic project examined human living conditions of Inuit, Saami and indigenous people of Chukotka. The referenced website includes protocols protecting the raw survey data, and conditions for access, which are evaluated on a case-by-case basis. The survey results allow quantitative comparisons of the consumption of marine resources in the North Slope, Northwest Alaska, and Bering Strait region.

State of Alaska Community Database Online
http://commerce.alaska.gov/cra/DCRAExternal

This website provides a brief and basic introduction to the history, culture, and contemporary living conditions in Alaska, including the communities in the PacMARS region.

U.S. National Park Service Shared Beringia Heritage Program
http://www.nps.gov/akso/beringia/
Contact: Janis Kozlowski (National Park Service) janis_kozlowski@nps.gov

The U.S. National Park Service funds projects of scientific and community importance in the Beringia Region of western Alaska and Chukotka. The projects are typically local community-based, and relatively small in scope. A complete list of current projects is available at the program web site. The PacMARS analysis considers these projects to be important even at a small scale as they contribute to maintaining neighboring community continuity throughout the Beringia region.

G1.6 Multidisciplinary Programs

AKMAP – Alaska Monitoring and Assessment Program
Web address: http://www.dec.state.ak.us/water/wqsar/monitoring/AKMAP.htm
POC (general): Terri Lomax, dec.akmap@alaska.gov, 907-269-7635, Doug Dasher, dhdasher@alaska.edu, 907-347-7779

The Alaska Monitoring and Assessment Program (AKMAP) is a state-sponsored water survey effort that includes inland and marine waters of Alaska. It is a component of the national Environmental Protection Agency's National Aquatic Resource Surveys http://water.epa.gov/type/watersheds/monitoring/aquaticsurvey_index.cfm/
The most relevant surveys within Alaska for PacMARS were studies in coastal waters of the Chukchi Sea in 2010-2012. These studies are considered to be still in progress, but scientists in this program have shared cruise reports and preliminary data have been presented in public meetings such as the Alaska Marine Science Symposium. Cruise reports and some of these data presentations are available at http://www.dec.state.ak.us/water/wqsar/monitoring/chukchisea.html/

We consider the data from this project to be critically important for understanding coastal processes in the Chukchi Sea that have only been poorly sampled in other research programs that have worked further offshore, such as the Bureau of Ocean Energy Management's COMIDA project. Similar research approaches were used, so the biological inventories and ecosystem data should allow for better understanding of the larger Chukchi ecosystem. Data from the AKMAP program are not readily available now, but will be included in the SOAR project focused on effects of prey dispersion, sea ice and walrus foraging in critical migration corridor for threatened eider ducks. A final report for the AKMAP the project is expected in 2014.

ANIMIDA - Arctic Nearshore Impact Monitoring in Development Area
(cANIMIDA – Continuation of Arctic Nearshore Impact Monitoring in Development Area)
Web address: http://www.duxbury.battelle.org/cANIMIDA/home/index.cfm/

The Arctic Nearshore Impact Monitoring in Development Area (ANIMIDA) was a five-year study, funded by BOEM, that began in 1999, and provided baseline data and monitoring results to evaluate potential effects from site-specific production in the Beaufort Sea. The Continuation of Arctic Nearshore Impact Monitoring in Development Area (cANIMIDA) was a continuation of this effort, and included sampling from 2004 until 2007. Field efforts included sampling for turbidity, total suspended sediment, and current velocity measurements. Sediment and suspended sediment samples were analyzed for polyaromatic hydrocarbons, saturated hydrocarbons, chemical tracers, trace metals, and supporting geophysical measurements. Biota sampling included similar chemical measurements in clams, amphipods, deployed mussels, and fish. A well-organized program database that is now accessible via the referenced web site, and includes data, reports, and bibliographical information for published papers. Data and overall understanding of the Beaufort Sea that are derived from this project were important to the PacMARS.

AOS-94 Arctic Ocean Section

Some of the findings of the 1994 US-Canadian crossing of the Arctic Ocean are summarized in the book "The 1994 Arctic Ocean Section – the first major scientific crossing of the Arctic Ocean," which can be downloaded at www.crrel.usace.army.mil/library/specialreports/AOS_SR96_23.pdf. Peer-reviewed results were published in a special issue of Deep-sea Research II (1994 Arctic Ocean Section, Volume 44, Number 8, 1995), and also in a number of subsequent publications in other peer-reviewed journals, including results supported by the ANWAP program on radioactive contaminants in sea ice, water column and sediments. Much of these data have been archived in the NSF supported ARCSS data archive that is now housed with EOL (http://www.eol.ucar.edu/projects/arcss/). The study was motivated by the need for improving “the observational base necessary for better understanding the role of the Arctic in global change”. The regional coverage is on the northern end of the PacMARS focus area and contributes to understanding the changes in physics and biology at the shelf-basin transition.

ArcticNet
http://www.arcticnet.ulaval.ca/
POC (general): Louis Fortier, louis.fortier@bio.ulaval.ca, +1-418-656-5646

ArcticNet is probably the largest single current Canadian Arctic research program and is structured through Centers of Excellence that includes research on natural, human health and social sciences in partnership with Inuit organizations, northern communities, federal and provincial agencies and the private sector. Specific objectives include studying the impacts of climate change and modernization in the coastal Canadian Arctic. Of interest to the PacMARS synthesis, in particular are research cruises that have been undertaken from the CCGS Amundsen in the Canadian Beaufort Sea, including participation of international and Canadian scientists. Current Beaufort Sea projects funded through ArcticNet are described at: http://www.arcticnet.ulaval.ca/research/iris_1.php

ArcWEST - Arctic Whale Ecology Study
http://www.boem.gov/akstudies/

The Arctic Whale Ecology Study (ArcWEST), funded by BOEM, is determining relationships between dominant currents passing through the Chukchi Sea and resources delivered to the Barrow Arch area and will provide information about the dynamic nature of those relationships relative to whale distribution and habitat utilization in the eastern-Chukchi and extreme western-Beaufort seas. The objectives of the project are to assess spatial and temporal patterns of use of the Chukchi Sea by endangered bowhead, fin and humpback whales, and beluga and gray whales, to assess population structure and origin of animals, to evaluate ecological relationships for the species, including physical and biological oceanography, and to extend existing studies of bowhead whale foraging ecology into the Chukchi Sea to further understand the sources, transport and advection of krill from the Bering Strait. This study utilizes technologies including satellite tracking, passive acoustic monitoring, genetic analyses, and oceanographic and biological methodologies and technologies. Further information is available in the publication: Friday, N.A., P. J. Clapham, Berchok, C. L. Crance, A. N. Zerbini, B. K. Rone, A. S. Kennedy, P.L. Stabeno, and J.M. Napp. 2013. Arctic Whale Ecology Study (ARCWEST): Use of the Chukchi Sea by endangered baleen and other whales (Westward Extension of BOWFEST). Annual Report. Submitted to BOEM under Interagency Agreement M12PG00021. 8 pp.

BERPAC - Program for long-term ecological research of ecosystems of the Bering and Chukchi Seas and the Pacific Ocean
http://www.lib.noaa.gov (search term BERPAC)

In 1972, the United States and the Soviet Union signed an Agreement on Cooperation in the Field of Environmental Protection. The Agreement was renegotiated in 1994 with the Russian Federation as the successor signatory. Three major research cruises involving U.S. and Russian scientists were undertaken in 1976, 1984, 1988, and 1993 and work areas crossed the U.S. – Russian boundary in the Bering and Chukchi Seas. The US Fish and Wildlife Service played a key role in coordinating these multidisciplinary cruises, and proceedings from each cruise have been published in both English and Russian. An English language 292 page proceedings volume providing results from the 1993 cruise is available, at no charge , from Steve Kohl, FWS via email steven_kohl@fws.gov or postal mail: Office of International Affairs, Division of International Conservation, U.S. Fish and Wildlife Service, 4401 North Fairfax Drive, Room 100, Arlington, VA 22203, USA

Particularly for the later cruises in the series in 1988 and 1993, some data were incorporated into peer-reviewed papers that were published as part of the ISHTAR and related programs, and some of these data will be integrated in the SOAR benthic-focused project (Appendix G2). Other data archiving is uneven; zooplankton data are archived at www.iobis.org under data provider ArcOD.

BEST - Bering Sea Ecosystem Study
http://bsierp.nprb.org/
http://www.eol.ucar.edu/projects/best/

Work during the Bering Sea Project, which includes both the National Science Foundation supported Bering Sea Ecosystem Study (BEST), and the North Pacific Research Board supported Bering Sea Integrated Ecosystem Research Program (BSIERP), was multidisciplinary and extended to all ecosystem parameters including biology, chemistry, and physics. The regional coverage included the Eastern Bering Sea shelf between the Aleutians and St. Lawrence Island. The study began in 2007 and is currently in its synthesis phase with several special issues published or in preparation. A number of PacMARS investigators were involved in this study, so although the area of study was for the most part to the south of the PacMARS study area, we are confident that collectively we can use knowledge being gained as research publications arise from BEST and BSIERP to advance our understanding of the PacMARS study area.

BOWFEST/SNACS
http://www.afsc.noaa.gov/NMML/cetacean/bwasp/flights_BOWFEST.php
POC(s): Julie Mocklin, <julie.mocklin@noaa.gov>, Carin Ashjian <cashjian@whoi.edu>

BOWFEST was a multiyear study started in 2007 that focused on late summer oceanography and prey densities relative to bowhead whale distribution over continental shelf waters within 100 miles north and east of Point Barrow, Alaska. BOWFEST was supported by the Bureau of Ocean Energy Management (BOEM) and other agencies, and included scientists from the National Marine Mammal Laboratory, Woods Hole Oceanographic Institute (WHOI), University of Rhode Island, the University of Alaska Fairbanks, the University of Washington, and Oregon State University, as well as local agencies and stakeholders on the Alaska North Slope. The NSF-funded Study of the Northern Alaska Coastal System (SNACS: 2005-2006) preceded BOWFEST and also focused on late summer oceanography and prey densities relative to bowhead whale distributions. Aerial surveys and acoustic monitoring were integrated with oceanographic sampling to help identify sources of zooplankton prey in conjunction with physical oceanographic processes that would make them available for whale feeding. An overall goal of the project was to understand bowhead whale behavior and distribution so that potential impacts from petroleum development activities can be minimized. Several PacMARS investigators have been involved in these studies and data from the that effort are included in their synthesis components.

BOWFEST/SNACS projects will be incorporated in several SOAR papers (Appendix G2). Because the project directly involved local stakeholders in Barrow and elsewhere on the North Slope, we consider this to be an excellent case study that improves understanding of ecosystem features through involvement of local communities. Zooplankton data from this study were incorporated into the PacMARS synthesis. See also SNACS entry and website link, annual reports are available on that website.

BSEO - Bering Strait Environmental Observatory
Web address: Discontinued

This National Science Foundation project involved fieldwork from 2000-2005 with three components: 1) shipboard sampling at key locations in the Bering Strait region in the water column and in the benthos 2) Marine mammal tissue archiving and sampling following subsistence hunting efforts at Diomede, with distribution of tissues for scientific research and 3) pilot-scale in-situ pumping of surface seawater at Diomede to document tracer and nutrient distributions flowing through the Bering Strait in winter and summer. The shipboard sampling program has been succeeded by the Distributed Biological Observatory (described below) and shipboard data have been transferred to the EOL data archive from CCGS Sir Wilfrid Laurier cruises from 1998-2012. Tissue samples and data from the subsistence hunting program have been published in a wide variety of peer-reviewed publications and the in-situ water column data were presented in a paper published in Arctic in 2006.

C3O - Canada's Three Oceans
http://www.dfo-mpo.gc.ca/science/Publications/article/2008/17-06-2008-eng.htm

Canada's Three Oceans Project was formally initiated as a Canadian contribution to the International Polar Year, and involved an intense sampling effort in 2009 during the IPY activities using two Canadian icebreakers sailing from Victoria, B.C. (sailing north and east) and Halifax (sailing north and west). Papers resulting from this work have been submitted to a special issue of the Journal of Geophysical Research. Some work was initiated prior to IPY and has continued afterwards. In the PacMARS region, U.S., Japanese, and Canadian scientists have participated in annual cruises of the CCGS Sir Wilfrid Laurier. Benthic biology and water column sampling is now being continued as part of the Distributed Biological Observatory (described below) and data from these annual cruises starting in 1998 are being made available as a result of PacMARS efforts at the EOL data archive.

cANIMIDA - Continuation of Arctic Nearshore Impact Monitoring in Development Area (ANIMIDA); http://www.duxbury.battelle.org/cANIMIDA/home/index.cfm/

See the description of this continuation project, above, under ANIMIDA in the multidisciplinary project section of this appendix. This project is wholly funed by BOME and is an important source of data and observations for the Beaufort Sea. Several PacMARS investigators have been funded through this project.

CASES - Canadian Arctic Shelf Exchange Study
http://cases.quebec-ocean.ulaval.ca/welcome.asp

This well-documented Canadian project that accomplished work in the Beaufort Sea between 2002-2004, including an overwinter freeze-in of the CCGS Amundsen, which is of relevance to PacMARS. Much of the work has been published; a bibliography is available at http://www.aina.ucalgary.ca/scripts/minisa.dll/144/proe/proeaa/bi%2Bcases?COMMANDSEARCH, data archiving is not centralized and varies by principal investigator

CFL – Circumpolar Flaw Lead Study
http://www.ipy-api.gc.ca/pg_IPYAPI_029-eng.html,
http://umanitoba.ca/faculties/environment/departments/ceos/research/cfl.html
POC: Dave Barber, dbarber@cc.umanitoba.ca

The Circumpolar Flaw Lead project during IPY was an international framework that investigated flaw leads, including one to the west of Banks Island in the Canadian Beaufort Sea. It was the largest IPY project in Canada (in research funding) and it examined how physical changes affect biological processes within leads. The system was studied throughout its yearly cycle, to determine the effects of global warming. An overview paper on the project was published as a contribution to a special section (Atmosphere-Ocean, Volume 48, Issue 4, 2010) highlighting Canadian marine activities during the IPY.

A number of other papers are now being published in a variety of peer-reviewed journals (suggested search term at http://scholar.google.com - Canadian Flaw Lead Study). For the PacMARS synthesis effort, these recent papers have only been imperfectly incorporated into our understanding of the Beaufort Sea ecosystem in relation to work in US waters. More integrative effort to compare and contrast the systems is needed.

CHAOZ- Chukchi Acoustic, Oceanographic, and Zooplankton Study
http://www.afsc.noaa.gov/NMML/cetacean/bwasp/index.php
POC: Catherine Berchok, Catherine.Berchok@noaa.gov; Phyllis Stabeno Phyllis.Stabeno@noaa.gov

In 2010, the NOAA Alaska Fisheries Science Center (AFSC) and the Pacific Marine Environmental Laboratory (PMEL) entered into a multi-year interagency agreement with the Bureau of Ocean Energy Management, Regulation, and Enforcement (now BOEM) to document the distribution and relative abundance of bowhead, humpback, right, fin, gray, and other whales in areas of potential seismic surveying, drilling, construction, and production activities and relate changes in those variables to oceanographic conditions, indices of potential prey availability, and anthropogenic activities. CHAOZ Annual Reports are available at the website above; data from the CHAOZ project will be incorporated in several SOAR analyses, especially the Acoustic Ecology project (SOAR, Appendix G2).

CHINARE - Chinese Arctic Expeditions
http://www.chinare.gov.cn/en/

The Chinese Arctic and Antarctic Administration, through the Polar Research Institute of China and cooperating universities, has becoming increasingly active in sponsoring Arctic shipboard research using the Xuelong (Snowdragon), which was purchased from Ukraine in 1993. The Chinese government is also building a second icebreaker for use in the Arctic and Antarctic. The 2009 expedition during the International Polar Year worked in the PacMARS study area and has documented sea ice conditions, biological communities, microbiological features, geochemistry, and dissolved organic dynamics. Many of the results have been published in a special issue of Deep-sea Research (http://www.sciencedirect.com/science/journal/09670645/81/supp/C). The Chinese contributions to scientific knowledge in the PacMARS area are becoming increasingly important and fill important gaps in data and temporal coverage. In some cases, since the Chinese scientists are generally new to the area, knowledge of past work is uneven, but U.S. scientists are also unfamiliar with these new research initiatives. It is clear that successfully integrating the new knowledge and progress being made by Chinese scientists is an important near-term goal.

COMIDA CAB - Chukchi Offshore Monitoring in Drilling Area (COMIDA) Chemical and Benthos (CAB); http://comidacab.org/

PacMARS PIs at CBL, FIT, URI, UTMSI, and WHOI have been funded through the recently completed Chukchi Offshore Monitoring in Drilling Area (COMIDA) Chemical and Benthos (CAB) program, funded by BOEM that evaluated the overall ecosystem condition of the northeast Chukchi Sea shelf. Scientific data are archived at the National Oceanic Data Center with a redundant archive at the University of Texas at Austin; a special issue of Deep-Sea Research has been published (Dunton et al. 2014; Deep-Sea Res II 102, 1-8). Goals of the project include discerning the base state of the ecosystem prior to oil and gas exploration so that future changing conditions resulting from oil and gas extraction, including biological features, contaminant distributions, and hydrographic patterns can be understood and distinguished from changes that may be due to climate change. Because of the widespread participation of PacMARS investigators in this project, we are confident that initial important findings are integrated into the current understanding of the Chukchi shelf ecosystem.

COMIDA HS - Chukchi Offshore Monitoring in Drilling Area (COMIDA) Hannah Shoal (HS) Ecosystem Study; http://comidacab.org/hannashoal/

The Hanna Shoal project, funded by BOEM, is a continuation of the original COMIDA project, described immediately above that is focused on Hanna Shoal northwest of Barrow. This shallow water feature affects current flow coming from the southwest and around the north side of Hanna Shoal. It is also an area where late summer remnant sea ice is often present and used by walruses as resting platforms from which to feed. Studies currently underway are multidisciplinary and include sedimentation, contaminants, surveys of epibenthic and infaunal biological communities, foodweb structure, physical oceanography, and water column biology.

CSESP- Chukchi Sea Environmental Studies Program
http://www.chukchiscience.com/StudytheScience/tabid/215/Default.aspx;
http://www.fairweatherscience.com/reports/Reports/tabid/184/Default.aspx

The Chukchi Sea Environmental Studies Program (CSESP) is a multi-year, multi-discipline marine science research program in the northeastern Chukchi Sea funded by a consortium of oil and gas companies, specifically ConocoPhillips Company, Shell Exploration and Production Company and Statoil USA E&P Company. Since 2008, the program has collected information on physical oceanography, ocean acidification, atmospheric conditions, sediments, contaminants, benthic (epifauna and infauna), plankton ecology (zooplankton, phytoplankton, and primary production), fish, seabirds, marine mammals, and, underwater acoustics. The CSESP website provide access to science summaries, outreach product, and project presentations. Data from the 2008-2012 field seasons are available on the Alaska Ocean Observing System website (http://www.aoos.org/industry-arctic-data/) for analyses and various data sets were used in the present synthesis activity are also available via the PacMARS data site. For the PacMARS study area, these data were a rich resource, although the short duration of the PacMARS synthesis project limited the capacity to fully assimilate the contributions made by the intense scale of the sampling in areas that may be impacted by oil and gas extraction. The SOAR Acoustics Ecology project includes data from this source, in combination with recordings support by Cornell University, Scripps Institution of Oceanography, NOAA/NMML and NSF/AON. A recent volume of Continental Shelf Research, Volume 67 (2013) has multiple scientific articles covering the results from this program.

DBO - Distributed Biological Observatory
http://www.arctic.noaa.gov/dbo/

The "Distributed Biological Observatory (DBO)" is a *change detection array* observatory built along a latitudinal gradient extending from the northern Bering Sea to the Barrow Arc, primarily funded by NSF, NOAA, and to a limited extent BOEM, along with international projects. DBO sampling is focused on transects centered on locations of high productivity, biodiversity and rates of biological change. The DBO sampling framework was initially tested during the successful 2010 Pilot Study, which consisted of international ship occupations of two of the DBO sites, one in the SE Chukchi Sea and one across upper Barrow Canyon. Notably, several U.S. agencies have endorsed the DBO concept in the Arctic research planning documents, including: (1) the 2010 NOAA Arctic Strategic Plan, (2) aspects in the BOEM Alaska Region planning efforts in the Chukchi Sea (COMIDA-Hanna Shoal), (3) statements in the recent USGS Science "Needs to Inform Decisions on Outer Continental Shelf Energy Development in the Chukchi and Beaufort Seas Alaska" document, and (4) interest by the Shell-ConocoPhillips-Statoil environmental program. Perhaps most importantly, the DBO is specifically included in the draft US National Ocean Policy Strategic Plan. In addition, the Marine Working Group of the International Arctic Science Committee (IASC) has endorsed the DBO and is supporting similar activities in the Atlantic sector of the Arctic. PacMARS PIs Cooper and Grebmeier are NSF-funded lead PIs for the project. The US Interagency Arctic Research Policy Committee (IARPC) DBO Collaboration Team, comprised of a number of academic researchers and leads of US agencies (e.g. NSF, NOAA, NASA, BOEM, ONR) has a goal of full-implementation of the DBO by 2015.

ICESCAPE - Impacts of Climate change on the Eco-Systems and Chemistry
http://www.espo.nasa.gov/icescape/
Lead contact: Kevin Arrigo, arrigo@stanford.edu

ICESCAPE was a NASA-funded program studying the impacts of retreating seasonal sea ice in the Chukchi Sea. A few papers have been published so far including a short article in Science documenting a productive under-ice phytoplankton bloom. Two field seasons using the USCGC Healy collected data, including studies of light penetration through ice and seawater, oceanographic features and ground truthing of satellite imagery. A suite of manuscripts have been submitted for a special issue of Deep-Sea Research II that will describe results from the program. At this time, data from the project are not openly available for outside-project use, although chlorophyll data was used in the PacMARS synthesis (several PacMARS PIs are also co-investigators on ICESCAPE).

IPY - International Polar Year
http://www.icsu.org/publications/reports-and-reviews/ipy-summary

A summary, 724-page report that documents polar research activities in 2007-2008, including an executive summary, planning, research, observations, outreach and legacies is downloadable from the referenced website. This report covers activities in both the Antarctic and Arctic by numbered IPY projects that were international and circumpolar in implementation. This volume includes short, preliminary findings from a number of relevant IPY projects in the PacMARS study area, including information on the Bering Strait inflow, the Canada Three Oceans Program, RUSALCA and Bering Sea programs such as BEST. While other sources of information exist for these projects, the integration of the preliminary IPY project results from the PacMARS study area with other arctic research projects is helpful and convenient.

ISHTAR - Inner Shelf Transfer and Recycling
http://www.lib.noaa.gov/uhtbin/cgisirsi/x/x/0/5?searchdata1=ISHTAR&Submit=Find

Inner Shelf Transfer and Recycling (ISHTAR) was a National Science Foundation project with fieldwork undertaken in 1984-1988. A special issue of Continental Shelf Research (ISHTAR: Inner Shelf Transfer and Recycling in the Bering and Chukchi Seas, Volume 13, Issues 5-6, ISSN 0278-4343) includes some of the key findings of the project, although other results were published in Marine Ecology-Progress Series, Science, and other peer-reviewed outlets. The project was originally designed to be an investigation of the influence of Yukon River on the Bering Sea, with the possibility of comparing the system with the Rhine River influence on the North Sea, but the key results of the project included documenting the source and fate of high nutrient fields associated with Anadyr water flowing north from the Bering Sea into the Chukchi Sea and demonstration of the importance of the benthos to the overall ecosystem. This project also coincided with improvement in relations between the United States and the Soviet Union and ISHTAR was able to initiate some of the first comprehensive cross boundary studies in both the Bering and Chukchi Seas. Some archived data are available from the IMS archive (described above) at the University of Alaska Fairbanks and paper copies of project and cruise reports are available at NOAA libraries, e.g.
http://www.lib.noaa.gov/uhtbin/cgisirsi/x/x/0/5?searchdata1=ISHTAR&Submit=Find

JWACS-Joint Western Arctic Climate Study
The Joint Western Arctic Climate Study (JWACS) is an evolving scientific collaboration of researchers from Canada, the United States, Japan and China, working in the Canadian Basin and Beaufort Gyre, and

using Canadian icebreaker assets and ice-anchored sensors. Goals have included examining the impacts of climate variability on oceanographic processes, variation in freshwater storage in the Beaufort Gyre, as well as atmospheric science, and biological observations. The history, publications, and other information about the project are presented on the Woods Hole Oceanographic Institution's Beaufort Gyre Exploration Project (http://www.whoi.edu/page.do?pid=66296). The US participation in the project is being supported through the Arctic Observing Network, so physical and chemical sensor oceanographic data, as well as modeling results are readily available at the referenced website.

Malina Project
http://malina.obs-vlfr.fr/

The Malina Project is focused on how changes in ice cover, permafrost and UV radiation impact on biodiversity and biogeochemical fluxes in the Arctic. Much of the field work was accomplished in the Beaufort Sea in cooperation with Canadian researchers in ArcticNet, but this French based program also played a role on the NASA funded ICESCAPE program in the Chukchi Sea in 2010-2011 (see ICESCAPE entry). Presentations, documents and data on the website for the project are password protected, but many data have been published in 2012-2013 in a special issue of Biogeosciences-Discussions (http://www.biogeosciences-discuss.net/special_issue80.html), which is an interactive open access journal of the European Geosciences Union, so data results are open to all and provide new insights on how reductions in sea ice are changing mineralization rates for dissolved organic matter in the upper water column, in addition to related topics.

MIZEX West: Bering Sea Marginal Ice Zone Experiment

An early marginal ice zone investigation in February 1983, this physics study helped promote understanding of sea ice formation processes in the Bering Sea, wind forcing, the development of polynyas, and atmospheric connections. A description of the program was published in the Transactions of the American Geophysical Union, EOS (DOI: 10.1029/EO064i040p00578). The primary study area was south of the PacMARS study, but clearly the sea ice processes worked out during this study are relevant to PacMARS.

NBS SLIP - Northern Bering Sea projects (St. Lawrence Island Polynya)
http://arctic.cbl.umces.edu

These were several NSF funded research projects that PacMARS PIs Grebmeier and Cooper served on as investigators in the north Bering Sea between 1989-2008, including work with J. Lovvorn (Southern Illinois University). These data have been used in the PacMARS synthesis with other data collected during BERPAC and BEST projects. Data are archived at EOL; for links to publications, see the referenced website.

RUSALCA - Russian American Long-Term Census of the Arctic
http://www.arctic.noaa.gov/aro/russian-american/
http://rusalcaproject.com/
POC: Kathleen Crane, Kathy.Crane@noaa.gov

The Russian-American Long-Term Census of the Arctic (RUSALCA) is the largest joint U.S. – Russian program for oceanographic research and was initiated following the signing of a memorandum of agreement between NOAA and the Russian Academy of Sciences in 2003. Focused on the Beringia region at the U.S. – Russian frontier, the results of the program are very important for understanding the regional scale of the ecosystem because of the difficulties of sampling in the Russian Exclusive Economic Zone without Russian scientific and governmental partners. Data from the program, which was initiated during a 2004 joint research cruise, followed by other multidisciplinary efforts in 2009 and 2012, are now being transferred to a data archive at the Alaska Ocean Observing System (see AOOS entry). Additional annual cruises have supplemented these multidisciplinary efforts through servicing of moorings in the Bering Strait. Several PacMARS investigators have been supported through the NOAA program, and we have incorporated data from the project into our overall synthesis.

SBI - Western Arctic Shelf-Basin Interactions
http://www.eol.ucar.edu/projects/sbi/
http://arctic.cbl.umces.edu/sbi/web-content/ (archived non-active site)

Shelf-Basin Interactions (SBI) was a scientific community designed program that developed into perhaps the largest interdisciplinary project in the PacMARS study area. It was supported by the National Science Foundation during 1999-2008. Assembled in three phases, the early retrospective and field portions were much larger in scope than a follow-on synthesis phase, so complete integration of the project results on exchange of organic materials on the outer continental shelf remains a work in progress, and peer-reviewed publications continue to be prepared, in addition to the contributions present in two special issues of Deep-sea Research. Data availabilities are generally good at EOL for this project, and several PacMARS investigators participated in the SBI project, so we think that important insights have been incorporated into our analysis. Data from SBI will be used in SOAR benthic and Barrow Canyon projects (SOAR; Appendix G2).

SHEBA - Surface Heat Budget of the Arctic
http://data.eol.ucar.edu/codiac/projs?SHEBA

The Surface Heat Budget of the Arctic (SHEBA) was an over winter freeze-in experiment in 1997-1998 using a Canadian icebreaker with US, Canadian and other international participation. During the overwinter experiment, this National Science Foundation-funded research project quantified heat transfer processes between the ocean and atmosphere. Other biological data collected during the experiment contributed to a better understanding of seasonal and annual changes in production and biological dynamics. Data from the project are available at the EOL and ArcOD archives. The project involved work well offshore (starting at a point 570 km north of Prudhoe Bay), and the core of the work involved consideration of surface albedo and heat exchange between the sea ice and atmosphere, so the data results are probably not as relevant to PacMARS as more recent multidisciplinary projects such as BEST and SBI.

SNACS - Study of the Northern Alaska Coastal System
http://www.arcus.org/arcss/snacs/
http://www.eol.ucar.edu/projects/arcss/

2005-2006
See BOWFEST; UAF, EOL, URI, UTMSI, WHOI were funded through this NSF project; data generally available; the remaining SNACS projects were primarily on land

G1.7 US Federal and State Agency Programs and International Organizations

ADF&G – Alaska Department of Fish and Game
http://www.adfg.alaska.gov//;

http://www.adfg.alaska.gov/index.cfm?adfg=marinemammalprogram.main, with recent professional papers covering pertinent topics such as bowhead whale migration routes and seasonal habitats http://www.adfg.alaska.gov/index.cfm?adfg=viewing.trackingmaps&map=bowhead.

The Synthesis of Arctic Research (SOAR) program anticipates two papers for the special issue of Progress in Oceanography, based in part on data from the bowhead tracking project (Appendix G2). Gray literature reports are less extensively available, and the professional paper sections are simply lists of papers in which ADFG employees were co-authors by year. Abstracts are generally unavailable and there are no tools on the website to download citations for compilation into bibliographical software libraries (e.g. .ris format files) that are common to most digital libraries. On the other hand, some portions of the website, including a searchable database of fishing and subsistence technical publications that can be downloaded as pdf files http://www.adfg.alaska.gov/sf/publications/ provide access to information resources unavailable elsewhere. Overall, the ADFG website suffers from a mix of needs, including serving the fishing and hunting public, providing outreach to meet layperson interest in the natural history of wildlife, proving for scientific users, and other agencies, NGOs, and public stakeholder constituencies. One result is that, while the value of the resource is high, it is clearly a challenge to extract all of the pertinent information that may benefit the PacMARS effort, including gray literature reports that are not online.

Alaska Center for Climate Assessment and Policy
http://ine.uaf.edu/accap/data_resources.html/

The website of the Alaska Center for Climate Assessment and Policy links to webinars, news stories, scenario and planning reports, policy documents, ongoing research projects and data resources held by other agencies – all intended to serve as resources for responding to Alaska's changing climate. Funded through NOAA, it is more of a clearinghouse than a source of original information not available elsewhere.

AON – Arctic Observing Network
http://www.arcus.org/search/aon
POC: Erica Key, ekey@nsf.gov

The Arctic Observing Network (AON) is the framework under which the National Science Foundation makes funding awards for projects in the Arctic that have an observational orientation. Projects include atmospheric, terrestrial and marine observations, and all funded investigators are required as a condition of funding to provide publicly accessible data to the ACADIS project, described above. The PacMARS analysis relied on several AON funded projects, which are described separately in the multidisciplinary narrative of this appendix. Data from various AON projects will also be incorporated in Synthesis of Arctic Research (SOAR) analyses and papers (Appendix G2).

AOOS – Alaska Ocean Observing System
Web address: http://www.aoos.org/
POC (general): Molly McCammon, mccammon@aoos.org, 907-644-6703

The Alaska Ocean Observing System (AOOS) has objectives of increasing access to existing coastal and ocean data, including providing access to information and data in visually useful packages. AOOS partnered with the PacMARS project to improve access to existing data using their web-based platform. The quality and quantity of data resources available through AOOS are increasing and the flexibility and power of the web-based platform have the potential to meet the needs of many stakeholders. The orientation of the AOOS platform is perhaps more towards highlighting real-time observations, including "low-hanging fruit," such as weather data also available through the National Weather Service, but temporal aspects of data display are being enabled, as are links to data storage. Specifically, the AOOS will provide a data visualization tool to the IARPC DBO IT; see IARPC and DBO entries.

ARC – United States Arctic Research Commission
Web address: http://www.arctic.gov/
POC (general): John Farrell, Executive Director; jfarrell@arctic.gov, 703-525-0113

The United States Arctic Research Commission was established by the Arctic Research and Policy Act of 1984 (as amended, Public Law 101-609). It is a small government agency that provides recommendations and supports efforts that establish national policy, priorities, and goals for the Arctic. Other goals include promotion of Arctic research, and to communicate research and policy recommendations to both the Executive and Legislative branches of the federal government though coordinated efforts that include five-year research plans. The ARC is primarily a higher level government coordinating agency, but it does contribute unique insights through workshop reports and other activities that involve researchers, agency representatives, and other stakeholders. The Commission's Report on Goals and Objectives for Arctic Research 2011-2012 http://www.arctic.gov/publications/2011-12_usarc_goals.html is a general resource that was consulted as part of the overall PacMARS effort.

ARCSS - Arctic System Science Section (NSF)
Arctic System Science (ARCSS) are projects funded by the National Science Foundation that take a systems approach to studying the Arctic. Projects relevant to PacMARS include multi-investigator projects such as Shelf-Basin Interactions and many individual projects. Data from completed NSF ARCSS projects are archived with the Earth Observations Laboratory, which is a unit of the National Center for Atmospheric Research, which is managed by the University Corporation for Atmospheric Research. Data are now housed in an ARCSS archive at EOL http://www.eol.ucar.edu/projects/arcss/, but will be eventually merged with ACADIS (described above). In addition, ARCSS/SBI data will be used in various SOAR projects (Appendix G2).

Arctic LSS - Arctic Landscape Conservation Cooperative
Web address: http://arcticlcc.org/
POC (general): Greg Balogh (Greg_balogh@fws.gov)

Landscape Conservation Cooperatives are an initiative led by the US Department of the Interior, which has responsibilities for national park, and wildlife refuge management, as well as other federally owned lands and resources. The mission statement of the Arctic Landscape Conservation Cooperative (ALCC) includes goals of identifying and providing information needed to conserve natural and cultural resources in the face of landscape scale stressors, particularly climate change. It is fundamentally a multidisciplinary program, supported by a steering committee and directed by a science plan (http://arcticlcc.org/about/scienceplan/), which supports coordinated actions among management agencies, conservation organizations, communities, and other stakeholders. Not all of the projects supported by the ALCC are relevant to PacMARS since the landscape protection components are often located in watersheds and on land, but we consider the ShoreZone mapping program and the Threatened Eider Database (http://arcticlcc.org/products/spatial-data/show/threatened-eider-geodatabase-for-northern-alaska-2012-edition to be two of several significant contributions of the ALCC that are relevant to the scope of the PacMARS effort. Another component of the program is the BIOMAP Alaska project, which is using local residents of Barrow, Kotzebue and Kaktovik to collect data on local observations, and upload that information via the web. Overall, ALCC is a program that is developing so not all information is readily available, such as the identity of investigators of individual ALCC projects.

BOEM - Scientific and Technical Publications

www.boem.gov/akstudies

The BOEM/MMS catalog of technical reports, charted by the year of their completion, includes a link to both natural and sociocultural studies funded by BOEM through the Alaska OCS (Outer Continental Shelf) Environmental Studies Program (OCSEAP). Pertinent projects for this synthesis are identified throughout this data document, such as ANIMIDA, ASAMM, CHAOZ, BOWFEST, and historic OCSEAP data. The sociocultural studies within the PacMARS study region cover primarily the Arctic Slope villages, offering very detailed accounts of the subsistence practices and offshore/onshore harvest areas in these communities.

Chariot – Cape Thompson Project Chariot

Web address: http://nwda.orbiscascade.org/ark:/80444/xv17795/ (link to description of paper archives of the project at the Rasmuson Library, University of Alaska Fairbanks)

The Project Chariot project was proposed as a means to construct an artificial deepwater port in northwestern Alaska by detonating nuclear explosives at Cape Thompson. The project was eventually abandoned, but not before stimulating an early campaign of ecological research to examine the potential consequences of this disruptive event. The key scientific record is the volume edited by Norman J. Wilimovsky and John N. Wolfe, The Environment of the Cape Thompson Region Alaska. U.S. Atomic Energy Commission, Government Printing Office, Washington, D.C. 1966. The book is widely available from academic libraries and can be purchased from www.amazon.com/. Much of the research that was conducted prior to the cancellation of Project Chariot project was terrestrial in origin, but some information is available in this volume on marine systems in the PacMARS study area. Given all of the marine research that has followed in subsequent decades, the description of the Chukchi Sea ecosystem in the volume seems of modest value for PacMARS objectives, although species inventories are of some value when assessing potential species range extensions over time.

Committee for the Workshop on Frontiers in Understanding Climate Change and Polar Ecosystems, Report of a Workshop, 2011

This workshop report is largely a research question resource. It considers issues on both land and sea and in the Antarctic as well as the Arctic.

IARPC - Interagency Arctic Research and Policy Committee

http://www.nsf.gov/geo/plr/arctic/iarpc/arc_res_plan_index.jsp/

POC(s): Brendan Kelly <Brendan_P_Kelly@ostp.eop.gov>; Sara Bowden, Executive Secretary, bowden@arcus.org

The Interagency Arctic Research Policy Committee (IARPC) is charged with developing five-year plans for federally sponsored research in the Arctic region. For 2013 to 2017, the IARPC, which consists of representatives from 14 Federal agencies, departments, and offices, has identified seven research areas that will inform national policy and benefit significantly from close interagency coordination; they include: (1) Sea ice and marine ecosystems; (2)Terrestrial ice and ecosystems; (3)Atmospheric studies of surface heat, energy, and mass balances; (4) Observing systems; (5) Regional climate models; (6)Adaptation tools for sustaining communities; and (7) Human health. IARPC Implementation Teams have been formed to coordinate inter-agency and academic approaches under each research area. The seven research areas do not encompass all Federal Arctic research activities that will occur over the next five years. Many important investigations outside the scope of this plan will continue to be conducted within individual agencies or through other interagency collaborations.

NOP - National Ocean Policy
http://www.whitehouse.gov/administration/eop/oceans/implementationplan/

The National Ocean Policy is a general, high-level policy document directing federal agency actions, based upon Executive Order 13547 -- Stewardship of the Ocean, Our Coasts, and the Great Lakes. The final Implementation Plan for the policy was released in April 2013 and can be downloaded at above site.

The Distributed Biological Observatory concept (described above) is specifically outlined for implementation of the National Ocean Policy: "

> "Implement a distributed biological observatory in the Arctic to monitor changes and improve our understanding of their socioeconomic and ecosystem impacts. The effects of Arctic changes and human activity on ecosystems and Alaskans who depend on them are poorly understood. Continued observations are needed to form a basis of understanding of the changing processes in the Arctic region. Agencies will continue to develop and deploy a distributed biological observatory, or an array of sites for consistent monitoring of biophysical responses in the Arctic marine environment, as a component of the integrated Arctic Observing Network. Regional collaboration and partnerships will increase our capacity to monitor and assess changing environmental conditions and support improved management of Arctic coastal and ocean resources."

NOPP: National Ocean Partnership Program
www.nopp.org

The National Oceanographic Partnership Program (NOPP) is a collaboration among federal agencies and other entities, academia, industry, and non-governmental organizations that support ocean research partnerships. This program supports ocean-related scientific and technical information nationwide. NOPP investments in the Arctic include several marine research projects, such as the Marine Arctic Ecosystem Study (MARES) for ecosystem studies in the Beaufort Sea, and the Arctic Marine Biodiversity Network (AMBON) to study biodiversity in the Chukchi Sea as part of a national network to monitor marine biological observations.

North Slope Science Initiative (NSSI)
http://northslope.org/
POC(s): John Payne, Executive Director, jpayne@blm.gov/; Dennis Lasseau, Deputy Director, dlassuy@blm.gov

The North Slope Science Initiative (NSSI) is an intergovernmental effort to increase collaboration at the local, state, and federal levels to address the research, inventory, and monitoring needs as they relate to development activities on the North Slope of Alaska. The NSSI has compiled a summary of long-term monitoring studies, which is supported by GINA (described above; also see http://northslope.org/monitoring/. This summary is comprehensive and not focused solely on the marine environment. Long-term monitoring is defined as multiple collections of the same variable over a period of 10 years or longer by comparable methodology on the North Slope of Alaska and in adjacent waters. Acceptable entries also include projects or initiatives that have been undertaken in the last five years that are intended to continue into the foreseeable future.

NOAA (National Oceanic and Atmospheric Administration) Arctic Theme Page
http://www.arctic.noaa.gov/

The NOAA Arctic Theme page is a general and extensive resource that provides a summary of current arctic status and includes links to the Arctic Report Card (discussed above), arctic research projects and online data supported by NOAA, and essays by researchers and local arctic residents. This is a well-developed thematic page that provides a mechanism for communicating synthetic knowledge of the Arctic in general and the PacMARS study region specifically.

NPRB – North Pacific Research Board
http://www.nprb.org/

The North Pacific Research Board is increasingly important as a facilitator of research priorities and funded science in the north Pacific, Bering Sea and north into the region considered during the PacMARS effort. While other examples are listed throughout this appendix, we cite a pertinent project specifically considered in development of our data synthesis and identification of research gaps. in addition to funding individual projects annually, NPRB also supports Integrated Ecosystem Research Programs.)

- **NPRB #503 Arctic Ocean Synthesis 2008;** http://doc.nprb.org/web/05_prjs/503_final.pdf/

  The North Pacific Research Board funded a Chukchi and Beaufort Sea synthesis project in 2008 that examined existing data sets with the intent of identifying research needs in the context of climate change, and to pose questions as a basis for future science initiatives. Although similar in inspiration to PacMARS, we have had the advantage of having access to the vast array of work that unfolded during the International Polar Year and additional funding has facilitated consideration of other factors such as contaminants and other chemical indicators that were only cursorily treated in this synthesis effort. PacMARS has also been tasked with consideration of human dimensions of Arctic change; NPRB Project #503 did not solicit significant local community input. Nevertheless the effort made was valuable and given the passage of time since preparation of this report, it is timely that we consider advancing these findings that are part of a tapestry of efforts that will help direct future research efforts in the north Bering, Chukchi, and Beaufort Seas.

OCSEAP - Outer Continental Shelf Environmental Assessment Program (Bureau of Land Management-NOAA)

The Outer Continental Shelf Environmental Assessment Program (OCSEAP) was a critical legacy program during the late 1970s that potentially provides a linkage and continuity for oceanic and biological conditions dating back to that period. The data are in uneven condition, some remain as paper records, although in some cases, the data can be accessed electronically, e.g. at http://www.ngdc.noaa.gov/mgg/geology/ocseap.html/. The Arctic Project Office for OCSEAP provided scientific management and coordination in the Beaufort, Chukchi Sea, and Hope Basin oil and gas lease areas. Paper records of the project office, which operated from 1975-1982, are archived in the Alaska Polar Regions Collections and Archives of the Elmer E. Rasmuson Library at the University of Alaska Fairbanks. The Alaska Resources Library and Information Services (see ARLIS entry above) in Anchorage also maintains paper copies of OCSEAP reports and results (description at: http://www.arlis.org/resources/special-collections/ocseap-reports/. Several PacMARS investigators are familiar with OCSEAP data and worked on the project or for OCSEAP investigators as graduate students. There no doubt remain important data legacies that could still be recovered, and the PacMARS effort reflects knowledge of "low-hanging fruit."

OER - Arctic Ocean Exploration cruises (NOAA)
http://oceanexplorer.noaa.gov/explorations/explorations.html/

The Ocean Exploration Program of NOAA has sponsored work that is relevant to PacMARS efforts, particularly the 2002 cruise of Louis St. Laurent (http://oceanexplorer.noaa.gov/explorations/02arctic/) and the 2005 cruise of the USCGC Healy into the Canada Basin http://oceanexplorer.noaa.gov/explorations/05arctic/logs/summary/summary.html/. Data from this cruise was used in support of the ArcOD component of the Census of Marine Life (see ArcOD entry above), as well as other efforts. PacMARS PI Bodil Bluhm participated on this cruise and is directing the ArcOD program from the University of Alaska Fairbanks, so we are confident that important insights from this program on arctic biodiversity have been successfully incorporated into the PacMARS effort. Macrofauna, megafauna and zooplankton 2002 data are archived at www.arcodiv.org and macrofauna 2005 data are archived at EOL on the PacMARS portal.

SAON - Sustaining Arctic Observing Networks
http://www.arcticobserving.org/

Sustaining Arctic Observing Networks (SAON) was initiated by the Arctic Council, meaning it is a high-level coordination effort. SAONB supports and strengthens the development of coordinated pan-Arctic observing and data sharing systems. However, SAON itself does not undertake science planning, conduct observations, or archive data, so in our PacMARS analysis, we did not make significant use of this developing resource for arctic observations.

Scaling Studies in Arctic System Science and Policy Support: A Call-to-Research
http://www.arctic.gov/publications/arctic_scaling.html

This report is the result of an Arctic Research Commission study on appropriate scaling for arctic research programs. The report was published in 2010 and can be downloaded at the referenced website. The report covered both terrestrial and marine systems, as well as human communities, infrastructure, resource extraction, ice navigation, and commercial and subsistence harvesting of food resources. A section on oil spill preparedness is clearly relevant to PacMARS efforts. Background reading and cited references were also included in this synthetic product with an applied orientation. (see also ARC above).

TOS – The Oceanographic Society
http://www.tos.org/oceanography/archive/24-3.html/

The Changing Arctic Ocean: Special Issue on the International Polar Year (2007–2009) is a published, freely available resource that provides a synthetic summary of the state of knowledge of a number of arctic oceanographic topics.

USFWS - US Fish and Wildlife Service
http://www.fws.gov/; http://www.fws.gov/alaska/mbsp/mbm/seabirds/seabirds.htm).

The U.S. Fish and Wildlife Service (USFWS) is responsible for all migratory birds, including marine birds that move from onshore breeding colonies to pelagic waters during the non-breeding season. As part of the survey and monitoring of breeding seabirds, the Alaska Marine National Wildlife Refuge (AMNWR) conducts surveys and supports a variety of studies throughout the state; results of these efforts, including diet information, are summarized in annual 'Breeding status and population trends' reports available at: http://www.fws.gov/alaska/nwr/akmar/whatwedo/bioprojects/publications.htm. The USFWS also maintains a seabird colony database available through http://seabirds.net/seabirdinfonetwork.html. The diet information associated with the Sebirds.net site is a work in progress, but will eventually link seabirds with their prey throughout the region and over time.

Kathy Kuletz is a key contact who is assisting PacMARS investigators with use of seabird data such as the North Pacific Seabird Database and Seabird Colony Database (see Seabirds.net entry below). We are also cognizant of rich data sets that are available from cross-boundary work of the Russia and East Asia Branch of the International Affairs office of the FWS. The associated BERPAC project is described above. Finally, FWS seabird data will be used in three SOAR studies: 1) nearshore benthic prey ; 2) marine bird and mammal distribution; and 3) trophic productivity at Barrow Canyon (SOAR; Appendix G2).

USGS – United States Geological Survey
USGS report on Outer Continental Shelf (OCS) science needs: An Evaluation of the Science Needs to Inform Decisions on Outer Continental Shelf Energy Development in the Chukchi and Beaufort Seas, Alaska: http://pubs.usgs.gov/circ/1370/pdf/circ1370.pdf/

This is an important predecessor study for PacMARS; it was predicated on improving the environmental assessments undertaken prior to oil and gas leasing and criticisms that these assessments were not up-to-date. In many ways, the PacMARS effort and this report used complementary approaches, with consideration of applied and technical issues with oil extraction, and more of a focus on higher trophic level birds and marine mammals in the USGS report.

USGS Changing Arctic Ecosystems initiative
http://alaska.usgs.gov/science/interdisciplinary_science/cae/index.php

The USGS Changing Arctic Ecosystems Initiative has been developed to enhance the long-term science needed to address many critical resource concerns, including: 1) information on wildlife species and their responses to ecosystem change to inform management decisions related to development of oil, gas and mineral resources on Bureau of Land Management lands and on the Outer Continental Shelf managed by Bureau of Ocean Energy Management; 2) Forecasting and mapping products to assist Department of Interior (DOI) land managers with maintaining viable natural ecosystems in the Arctic; 3) develop data and forecasting tools to inform critical DOI actions related to regulation or policy, such as related to the Endangered Species Act, Marine Mammal Protection Act, native subsistence and co-management actions; and 4) develop projections of habitat change and potential species responses to help agencies design new monitoring protocols or modify strategies to support adaptive management in a changing Arctic.

U.S. National Assessment Alaska Regions Bering Sea Impact Study (BESIS)
http://www.besis.uaf.edu/

This is a completed workshop from the 1990s. Several PIs are familiar with this project.

USN – United States Navy
http://www.navy.mil/navydata/documents/USN_artic_roadmap.pdf/

Note that "arctic" is misspelled on Navy website link to the above .pdf file.

US Navy Road Map

The US Navy Road Map is a potential resource for research questions, but the document is written for such specific issues as international security and/or at a general level so that the linkage to PacMARS goals are ambiguous.

USoDS - US State Department-Foreign Data Sets

The US State Department approves foreign vessel science requests, but there is no central repository for data that are collected by foreign vessels in the US Exclusive Economic Zone (EEZ). This is unfortunate because it limits communication of foreign vessel intentions for research in US waters near subsistence-oriented communities in Alaska.

WCCY - What is Climate Change to You?
http://2011.polarhusky.com/support/wccy/what-is-climate-change-to-you/

The PolarHusky "Go North" website is a valuable education website with resources for teachers and students.

G1.8 Arctic Data Portals and Library Resources

ACADIS - Advanced Cooperative Arctic Data and Information Service
Web address: http://www.aoncadis.org/home.htm
POC (PacMARS): James Moore (jmoore@ucar.edu)

The Advanced Cooperative Arctic Data and Information Service (ACADIS) is emerging as a key data archival service that is funded by the National Science Foundation (NSF). Investigators now funded through NSF Arctic research programs are increasingly being obligated as a condition of funding to share collected data through ACADIS. The data archive is also being used by other agencies and projects, and is directly serving PacMARS data retrieval efforts as a participating team member of the project. Strengths of the site include excellent geographical orientation displays and search tools. Some researchers remain hesitant to share data despite award conditions, so ACADIS should not be considered a completed effort that reflects all NSF-funded science in the Arctic. Data organization within the website by discipline and project also remains a work in progress.

Arctic Data portal
www.arcticdata.org

The Arctic data portal is a developing resource that serves as an archive providing access to data collected and developed through the activities of the Conservation of Arctic Flora & Fauna (CAFF) and Protection of the Arctic Marine Environment (PAME) Working Groups of the Arctic Council. High-quality maps and data displays are available for download, although the coverage is broadly pan-Arctic and some data and links, e.g. to AOOS, are available elsewhere.

Arctic EIS – Arctic Ecosystem Integrated Survey

Web address: https://web.sfos.uaf.edu/wordpress/arcticeis/
POC (general): Franz Mueter, fmueter@alaska.edu, 907-796-5448

The Arctic Ecosystem Integrated Survey (Arctic EIS) is a University of Alaska Fairbanks and Alaska Fisheries Science Center based effort that is contributing to a better understanding of the oceanography, lower trophic levels, crab, and fish communities of the northeastern Bering Sea and eastern Chukchi Sea shelf and evaluate results relative to earlier studies in the same area and relative to similar studies in adjacent regions. The work includes on-going and recent field sampling, laboratory analyses, development of geo-databases, and facilitation of data sharing and synthesis with other programs and investigators in the Chukchi Sea and adjoining ecosystems. Funding is provided by the Department of the Interior via the Fish and Wildlife Service and Bureau of Ocean Energy Management, with additional funds from NOAA, and the Alaska Department of Fish and Game. The results of this project will be of value for understanding foodweb structure and ecosystem function in the Chukchi Sea, but only limited results (e.g. copies of posters) are available at this time. Because of the contemporaneous efforts to collect data at the same time as the PacMARS synthesis, we do not expect to fully incorporate the ArcEIS results into our synthesis, but note the high potential this program should have for improving understanding of the Pacific-influenced Arctic. PacMARS PI Bluhm is a co-PI on this project.

Arctic ERMA – Arctic Environmental Response Management Application
POC (general): orr.erma@noaa.gov
Web address: http://response.restoration.noaa.gov/maps-and-spatial-data/environmental-response-management-application-erma/arctic-erma.html

https://www.erma.unh.edu/arctic/erma.html#x=-158.52172&y=69.38032&z=5&layers=12959+12913+12921+12920

The Environmental Response Management Application (ERMA) is a web-based Geographic Information System (GIS) tool funded by NOAA that is hosted at the University of New Hampshire with support from the EPA that is designed to facilitate emergency response and environmental resource managers in dealing with incidents that may adversely impact the environment. For example, currents, bathymetry, and environmental sensitivity indices are available as layers to help understand potential impacts of events such as oil spills or ship groundings. The data on the website are for the most part available from other sources, but the web-based tools the site provides are well-designed, with high functionality. We did not directly use the ERMA site in our PacMARS analysis, but recognize the value it brings to resource managers and its value for emergency response.

Arctic Report Card
Web address: http://www.arctic.noaa.gov/reportcard/
POC (general): Jana Goldman, jana.goldman@noaa.gov, 301-734-1123

The Arctic Report Card is now issued annually as a cooperative interagency effort led by NOAA. The document is peer-reviewed and edited prior to release, and summarizes current understanding of the state of the Arctic relative to historical records on a variety of topics. The Report Card is intended for a wide audience, including scientists, teachers, students, decision-makers and the general public interested in the Arctic environment and science. The Report Card is organized into five sections: Atmosphere; Sea Ice & Ocean; Marine Ecosystem; Terrestrial Ecosystem; and Terrestrial Cryosphere, and specialized topics are folded into the overall Report. Since the document is meant for widespread public use, PacMARS did not use it as a primary data source for its analysis, but several PacMARS investigators have been co-authors of the annual versions of the Arctic Report Card. We think the broad understanding of the state of the Arctic as reported in the Arctic Report Card is also reflected in the PacMARS analysis.

Arctic Science Portal
http://www.arctic.gov/portal/

The Arctic Science Portal includes links to other websites where Arctic data and general information are available, including many that are tabulated here. While it aspires to be comprehensive and cover all topics (e.g. economics, society, natural sciences), the Portal is a new resource that is still in development and must be considered a work-in-progress. It includes links to sites that are both active and inactive; explanations of organizations and acronyms are brief and in some cases not sufficient for casual users. Coverage of organizations is uneven, for example, a wide variety of web links are provided to Canadian government agencies, but only one to the each of the governments of Denmark, Iceland, Finland, Norway and Russia. Somewhat oddly, given the one link to Denmark, a separate link is also available to the government of Greenland. The data set portal links, at http://www.arctic.gov/portal/datasets.html are helpful and, with an appropriate investment, the Portal should become increasingly more valuable.

ARLIS - Alaska Resources Library and Information Services
http://www.arlis.org/

The Alaska Resources Library and Information Services (ARLIS) is a comprehensive library covering all information relating to Alaska's natural and cultural resources. A number of state and federal agencies, as well as the University of Alaska Anchorage and the Exxon Valdez Oil Spill Trustee Council are networked circulating supporters of the library's operations in Anchorage. Interlibrary loans are available to these agencies, as well as outside users, and the library can issue library cards and access upon written request, as well as through institutional affiliation. Electronic access to professional journals is available, and there are mechanisms for requesting access to professional journals that are otherwise prohibitively expensive for casual users, but in many cases, use is restricted to access from the library itself in Anchorage. While the Library is an extremely valuable resource for users without university affiliations, as part of PacMARS, we did not make significant use of the library because many of its resources were already available through our own institutional libraries and networks.

Arctic Marine Synthesis: Atlas of the Chukchi and Beaufort Seas
http://ak.audubon.org/arctic-marine-synthesis-atlas-chukchi-and-beaufort-seas The Atlas of the Chukchi and Beaufort Seas is a cooperative project completed in 2010 between Audubon Alaska and Oceana that provided a place-based summary of a number of important ecosystem variables, as well as distribution maps for birds that are on the Audubon Alaska watch list. The format of the project includes extensive use of geographical information system tools using the best available information. References to the original data sources are provided and assessments are provided on the quality of the data that were used to prepare the mapped products.

CADIS - Cooperative Arctic Data and Information Service
http://www.aoncadis.org
The Cooperative Arctic Data and Information Service (CADIS) is the designated repository for Arctic Observing Network data and is now transitioning to a wider data depository function for additional National Science Foundation projects that involve less observational data than the Arctic Observing Network program, such as individual and multidisciplinary NSF projects. This wider project function is described under ACADIS above.

EOL - Earth Observing Laboratory
http://www.eol.ucar.edu/data; Contact: Jim Moore, jmoore@ucar.edu

The Earth Observing Laboratory is a key partner in PacMARS, providing data archiving capabilities for the project in conjunction with other funded program activities such as ACADIS, described above.

JAMSTEC Data Research System for Whole Cruise Information
http://www.godac.jamstec.go.jp/darwin/e

Data from research cruises conducted by JAMSTEC (Japanese Agency for Marine-Earth Science and Technology) in the Bering and Chukchi Seas using the R/V Mirai are archived at this web site. Data cover physical, chemical, and some biological (e.g., chlorophyll) variables. Most of the data are available. Chlorophyll and CTD data were used in the PacMARS synthesis.

NODC - National Oceanographic Data Center (NOAA)
http://www.nodc.noaa.gov/

The National Oceanographic Data Center (NODC) is the largest global source of oceanographic data and includes data from the PacMARS study area. There are some complexities to achieving successful search engine results, and in some cases the data archived and associated metadata present limitations. For example, PacMARS efforts to use OCSEAP zooplankton data were limited because life stage data were not included in the archived data. Changes in taxonomic nomenclature have also posed difficulties for long-term data sets. Particularly for older data sets such as OCSEAP, the NODC archive is invaluable and should be explored further to document changes, despite the challenges that may be posed.

NSSC - North Slope Science Catalog (see GINA entry)
http://www.north-slope.org/departments/wildlife/studiesNresearch.php

NSSI - North Slope Science Initiative – see earlier entry at GINA
http://www.northslope.org/monitoring

OBIS - Ocean Biogeographical Information System
www.iobis.org

The Ocean Biogeographical Information System is a global database for biodiversity data that can be used for evaluation of the status of knowledge on ocean biodiversity, gaps, and potential for discovery. The database system receives foundation support under the umbrella of UNESCO's Intergovernmental Oceanographic Commission and it is a legacy of the Census of Marine Life, so please also see the entry under ArcOD for information that is specific to the Arctic Census of Marine Life. There are some limitations to use of these data. For example, abundance data are lacking in most instances, so understanding processes or population dynamics is beyond the current scope of the project. ArcOD data can be downloaded from OBIS directly (http://iobis.org/mapper/, view ArcOD data provider under 'datasets' in 'search data')

PANGEA (Publishing Network for Geoscientific & Environmental Data)
http://www.awi.de/en/infrastructure/computing_and_data_centre/old_information_systems/pangaea/

PANGAEA® is a repository for georeferenced data from earth system research, primarily in the Atlantic sector. Datasets are citable including a persistent identifier (DOI). The Alfred-Wegener Institute (AWI) together with MARUM operates the World Data Center for Marine Environmental Sciences (WDC-MARE) using PANGAEA as its central archive.

Thesis and Dissertation Project Database of the University of Alaska Resilience and Adaptation Program
http://www.uaf.edu/rap/students/Alumni/

This webpage provides links to theses by early career scientists who are alumni of the University of Alaska Fairbanks Resilience and Adaptation Graduate Program; some of these theses are clearly relevant to the PacMARS study area and the intersection with local traditional knowledge in some cases.

APPENDIX G2 - Synthesis of Arctic Research (SOAR) Products (December 2014)

PacMARS and SOAR have a collaborative effort, with SOAR faciliting data collections and identifying directions for future research and SOAR specifically developing synthesis publication. Many of the SOAR chapters utilizae PacMARS data sets (e.g., Grebmeier et al.). Notably, SOAR has an upper trophic focus, with over half of the chapters on marine bird and mammal responses (Figure G2.1), with 3 chapters on bio-physical relationships and 3 chapter on marine bird and mammal prey response. Table G2.1 list the titles and authors of the manuscripts.

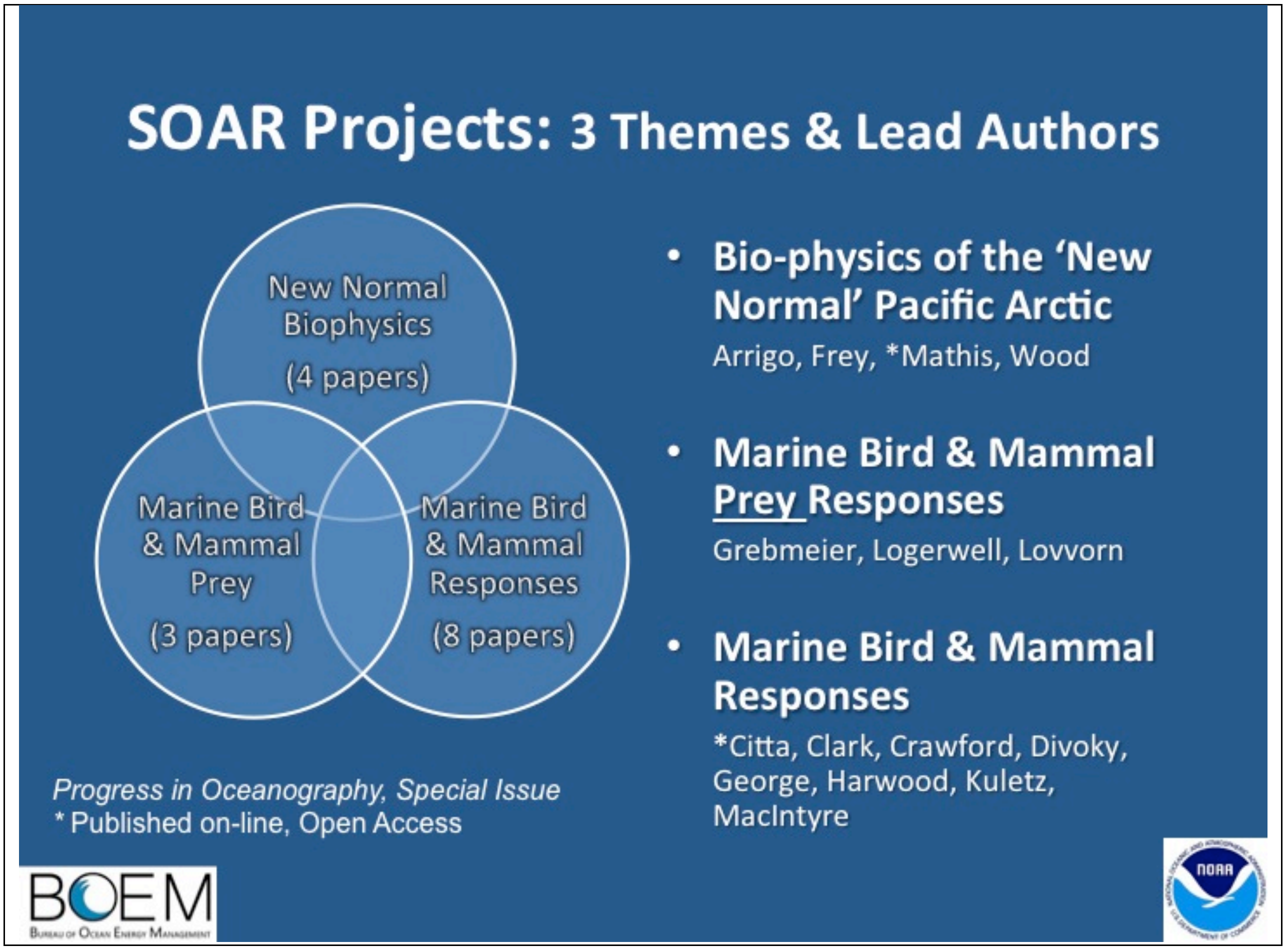

Figure G2.1. Summary of SOAR special issue chapters, as of December 2014.

Table G2.1. Synthesis of Arctic Research (SOAR) project status of publications for the pending special issue in Progress in Oceangraphy (as of December 22, 2014).

Themes

1.	The 'New State' of the Pacific Arctic sector: Observations & models of sea ice loss and effects on primary production
2.	Response of mid-level trophic species to the 'New State' of the Pacific Arctic: Benthic and pelagic invertebrates + forage fishes (cod, capelin, sand lance etc.)
3.	Response of upper-trophic species to the 'New State' of the Pacific Arctic: Marine mammal and seabird distribution, relative abundance and phenology

Progress in Oceanography SOAR Special Issue Papers

Theme 1. The 'New State' of the Pacific Arctic sector: Observations & models of sea ice loss, effects on primary production and acoustic ecology		
Lead Author	**Paper Title**	**Status**
Arrigo	**Continued increases in Arctic Ocean primary production**	**Accepted**
Frey	Recent regime shifts in sea ice cover across the Pacific Arctic region	In revision
Mathis	**Ocean acidification risk assessment for Alaska's fishery sector**	**Published: OPEN ACCESS**
Wood	A decade of environmental change in the Pacific Arctic region	In revision
Theme 2. Response of mid-level trophic species to the 'New State' of the Pacific Arctic: Benthic and pelagic invertebrates + forage fishes (cod, capelin, sand lance etc.)		
Lead Author	**Paper Title**	**Status**
Grebmeier	Benthic system analysis at predator-prey "hotspot" sites along a latitudinal gradient in the northern Bering and Chukchi seas	In revision
Logerwell	Fish communities across a spectrum of habitats in the Beaufort and Chukchi seas	In revision
Crawford	Responses of ringed and bearded seals to changes in the Pacific Arctic	In revision
Divoky	Effects of recent decreases in Arctic sea ice on an ice-associated marine bird	In revision
Lovvorn	Limits to benthic feeding by eiders in a critical Arctic migration corridor due to localized prey and changing sea ice	Revised

Table G2.1 Synthesis of Arctic Research (SOAR) project status of publications for the pending special issue in Progress in Oceangraphy (as of December 22, 2014) (cont.)

Theme 3. Response of upper-trophic species to the 'New State' of the Pacific Arctic: Marine mammal and seabird distribution, relative abundance and phenology		
Lead Author	**Paper Title**	**Status**
Citta	**Ecological characteristics of core-use areas used by Bering-Chukchi-Beaufort (BCB) bowhead whales, 2006-2012**	**Published: OPEN ACCESS**
Clark	A year in the acoustic world of bowhead whales in the Bering, Chukchi, and Beaufort seas	In revision
George	**Bowhead whale body condition and links to summer sea ice and upwelling in the Beaufort Sea**	**Accepted**
Harwood	**Change in the Beaufort Sea ecosystem: Diverging trends in body condition and/or production of five marine vertebrate species**	**Accepted**
Kuletz	Seasonal spatial patterns in seabird and marine mammal distribution in the Pacific Arctic: identifying biologically important pelagic areas	In revision
MacIntyre	**The relationship between sea ice concentration and the spatio-temporal distribution of vocalizing bearded seals (*Erignathus barbatus*) in the Bering, Chukchi, and Beaufort Seas from 2008-2011**	**Accepted**
Lead Author	**Paper Title**	
Moore & Stabeno	Synthesis of the synthesis	In preparation

APPENDIX G3. PacMARS Data Policy.

PacMARS Data Policy (December 2012)

The Pacific Marine Arctic Regional Synthesis research team and collaborators will identify and synthesize existing data sets that are critical for evaluating the current state of knowledge of the north Pacific ecosystem, including human dimensions. The PacMARS Data Archive will provide a central gateway to multiple data sets brought together for the data inventory and synthesis effort. The overall goal of the data synthesis is to document where relevant data resides and make these data available to the investigators.

As data sets are identified and/or reformatted for the synthesis effort they will be submitted to the data archive (pacmars.eol.ucar.edu). Instructions for doing so are linked off the main page of the archive. Datasets, or information on them when residing at another repository, must be submitted to the archive with sufficient documentation to allow easy exchange and understanding by others. The information on the datasets, or "metadata", is a key element when bringing together a diverse collection of data from multiple sources. It is important that users understand the attributes of the data as well as details about format. EOL will make available online forms and templates to assist in the collection of the metadata for the datasets.

Geographical information on the datasets will be plotted to the PacMARS Mapserver for discovery and visualization purposes. Researchers will submit shapefiles to the archive for display of the GIS data on the Mapserver, along with the metadata for the dataset.

Datasets from previous projects and those at other institutions will be linked from the PacMARS archive web site. Access to those data will be open, unless restricted by the host institution. If access to those data is especially difficult or time consuming, a decision will be made on a case-by-case basis whether to archive the data within the PacMARS Data Archive and provide access directly.

Any new datasets, such as those from recent cruises or the oil industry, will be password protected for the first year of the project and access limited to the PacMARS researchers. Human dimension datasets, and others of a sensitive nature, may remain password protected for a longer period. Individual PacMARS members may release their proprietary data to whomever they wish.

PacMARS team members should be contacted before use of their data sets. PacMARS investigators and others are responsible for providing appropriate recognition to data providers in publications. This can include article co-authorship and/or reference to data publications. Citations, and DOIs when available, will be provided for datasets within the EOL data archive.

APPENDIX G4. PacMARS Data Set Titles and Authors in the EOL Data Archive.

Dataset Title	Author/PI
Oil Industry Chemical Characterization Data	Battelle Memorial Institute, Exponent Inc., Florida Institute of Technology, Neff & Associates
Oil Industry Meteorological Buoys Data	Fairweather Leasing LLC
Oil Industry Marine Mammal Aerial Data	LGL Alaska Research Associates Inc.
Oil Industry Marine Mammal Monitoring Data	LGL Alaska Research Associates Inc.
Oil Industry Study Logistics Data	Olgoonik Fairweather LLC
Oil Industry Marine Mammal Ecology Data	Aerts, Lisanne, Jay Brueggeman, Andrew Cyr, Robert Gumtow, Willow Hetrick, Alex V. Kirk, Kate Lomac-MacNair, Sasha McFarland, Carissa S. Schudel, Pamela E. Seiser, Sioned Sitkiewicz, David Snyder, Bridget Watts
Detection of change in surface water areas and in their geographic distribution on St. Lawrence Island	Amstislavski, Philippe
Permanent open surface water areas in Nenets Autonomous Okrug, Russian Federation	Amstislavski, Philippe, Leonid Zubov, Herman Chen, Pietro Ceccato, Jean-Francois Pekel, Jeremy Weedon
Average Water Column Temperature, Summer, Gridded	Ashjian, Carin
Bottom Water Column Temperature, Summer, Gridded	Ashjian, Carin
Integrated Chlorophyll (0-100 m, mg m-2), Summer, Gridded	Ashjian, Carin
Zooplankton Data Sets used in Compilation	Ashjian, Carin
Integrated Chlorophyll (0-100 m, mg m-2), All Data	Ashjian, Carin
Phytoplankton Data Sets used in Compilation	Ashjian, Carin
Surface Water Temperature, Summer, Gridded	Ashjian, Carin
Zooplankton Abundance Compilation	Ashjian, Carin, Robert Campbell and Susan Mills
Environmental data for Macrobenthic sampling stations in Prudhoe Bay, Beaufort Sea 1974	Blanchard, Arnold L., Howard Feder
Environmental data for Macrobenthic sampling stations in the Chukchi Sea	Blanchard, Arnold L., Howard Feder

APPENDIX G4. PacMARS Data Set Titles and Authors in the EOL Data Archive (cont.)

Environmental data for Macrobenthic sampling stations in the Chukchi Sea	Blanchard, Arnold L., Howard Feder
Macrobenthic data from Nearshore Prudhoe Bay	Blanchard, Arnold L., Howard Feder
Macrobenthic data from the Chukchi Sea	Blanchard, Arnold L., Howard Feder
Macrobenthic data from Bering to Chukchi Sea 1970 to 1974	Blanchard, Arnold L., Samuel W. Stoker
Oil Industry Benthic Ecology Data	Blanchard, Arny L., Ann Knowlton, Carrie L. Parris
LSL2002-23 Macrofauna Data	Bluhm, B. A., I. R. MacDonald, C. Debenham, K. Iken
HLY-05-02 Macrofauna Data	Bluhm, Bodil A.
Epifauna Sampling Data	Bluhm, Bodil A.
WEBSEC-72 Trawl Data	Bluhm, Bodil A., Andrew G. Carey Jr., Susan Schonberg, Gordon Hendler, Philip Lambert
Animida and cAnimida Data	Brown, John S., Ken H. Dunton, Greg Durell, Michael Galginaitis, Jerry M. Neff, George W. Shepard, Robert B. Spies, John H. Trefry (Battelle)
Sir Wilfrid Laurier (SWL) Cruise Merged Chemistry Parameters (2000)	Cooper, Lee W. and Jacqueline M. Grebmeier
Sir Wilfrid Laurier (SWL) Cruise Merged Chemistry Parameters (2002)	Cooper, Lee W. and Jacqueline M. Grebmeier
Sir Wilfrid Laurier (SWL) Cruise Merged Chemistry Parameters (2003)	Cooper, Lee W. and Jacqueline M. Grebmeier
Sir Wilfrid Laurier (SWL) Cruise Merged Chemistry Parameters (2005)	Cooper, Lee W. and Jacqueline M. Grebmeier
Sir Wilfrid Laurier (SWL) Cruise Merged Chemistry Parameters (2001)	Cooper, Lee W. and Jacqueline M. Grebmeier
Sir Wilfrid Laurier (SWL) Cruise Merged Chemistry Parameters (2007)	Cooper, Lee W. and Jacqueline M. Grebmeier
Sir Wilfrid Laurier (SWL) Cruise Merged Chemistry Parameters (2008)	Cooper, Lee W. and Jacqueline M. Grebmeier
Sir Wilfrid Laurier (SWL) Cruise Merged Chemistry Parameters (2010)	Cooper, Lee W. and Jacqueline M. Grebmeier
Sir Wilfrid Laurier (SWL) Cruise Merged Chemistry Parameters (2012)	Cooper, Lee W. and Jacqueline M. Grebmeier
Sir Wilfrid Laurier (SWL) Cruise Merged Chemistry Parameters (2006)	Cooper, Lee W. and Jacqueline M. Grebmeier

APPENDIX G4. PacMARS Data Set Titles and Authors in the EOL Data Archive (cont.)

Sir Wilfrid Laurier (SWL) Cruise Merged Chemistry Parameters (2013)	Cooper, Lee W. and Jacqueline M. Grebmeier
Sir Wilfrid Laurier (SWL) Cruise Merged Chemistry Parameters (2004)	Cooper, Lee W. and Jacqueline M. Grebmeier
Sir Wilfrid Laurier (SWL) Cruise Merged Chemistry Parameters (2011)	Cooper, Lee W. and Jacqueline M. Grebmeier
Oil Industry Seabirds Data	Day, Robert, Adrian Gall, Tawana Morgan
Oil Industry Passive Acoustics Data	Delarue, Julien, Nicole E. Chorney, Heloise Frouin-Mouy, David Hannay, Jeff MacDonnell, Bruce Martin, Xavier Mouy, Jonathan Vallarta, Jennifer Wladichuk
Pacific Arctic Stable Isotope Synthesis	Dunton, Kenneth H.
Chukchi Sea Offshore Monitoring in Drilling Area (COMIDA): Chemical and Benthos (CAB)	Dunton, Kenneth H., Lee W. Cooper, Jacqueline M. Grebmeier, H. Rodger Harvey, Brenda Konar, David Maidment, Susan V. Schonberg, John Trefry
Summary Figures of Food Webs and Stable Isotopes	Dunton, Kenneth, Susan Schonberg, Timothy L. Whiteaker
Bowhead Whale Abundance	George, John C. "Craig", David Rugh, Robert Suydam, Judy Zeh
Regional Alaska Community Meetings	Grebmeier, Jacqueline M.
PacMARS Benthic Infaunal Parameters (1970-2012)	Grebmeier, Jacqueline M. and Lee W. Cooper
PacMARS Bottom Water Nutrients (1988-2012)	Grebmeier, Jacqueline M. and Lee W. Cooper
PacMARS Sediment Community Oxygen Uptake (1984-2012)	Grebmeier, Jacqueline M. and Lee W. Cooper
PacMARS Surface Sediment Parameters (1970-2012)	Grebmeier, Jacqueline M. and Lee W. Cooper
PacMARS Integrated Chlorophyll-a (1985-2012)	Grebmeier, Jacqueline M. and Lee W. Cooper
PacMARS Sediment Chlorophyll-a (1995-2012)	Grebmeier, Jacqueline M. and Lee W. Cooper
Oil Industry Zooplankton Ecology Data	Hopcroft, Russell R., Pallavi Hariharan, Jennifer Questel, Jesse Lamb, Evelyn Lessard, Mike Foy, Cheryl Clarke-Hopcroft
Walrus Monthly Foraging Utilization Distribution in the Chukchi Sea: 2008-2011	Jay, Chad and Anthony Fischbach
Oil Industry Chemical Oceanography Data	Mathis, Jeremy

APPENDIX G4. PacMARS Data Set Titles and Authors in the EOL Data Archive (cont.)

Exploratory Drilling Sites in the Chukchi and Beaufort Seas Offshore Alaska	Minerals Management Service
Oil Industry Fisheries Data	Norcross, Brenda L., Abby L. Antonelis, Kyle L. Antonelis, Stephen T. Crawford, Lorena EdenField, Benny J. Gallaway, Scott E. Goodman, Brenda A. Holladay, Jeffrey A. June, Robert M. Meyer, Justin T. Priest, Scott W. Raborn
CTD Summary Data	Okkonen, Stephen R.
COMIDA Biota Contaminants	Trefry, John H.
COMIDA Sediment Contaminants	Trefry, John H.
Industry Chukchi Sea Sediments 2009 and 2010	Trefry, John H.
Coastal Marine Insitute University of Alaska Sediment Data	Trefry, John H.
Industry Data for Chukchi Sea 2008 Burger and Klondike Sediments	Trefry, John H.
Camden Bay Industry Sediments	Trefry, John H.
Industry Data for Chukchi Sea 2008 Burger and Klondike Biota Contaminants	Trefry, John H.
ANIMIDA Sediment Contaminants	Trefry, John H. and Robert P. Trocine
cANIMIDA Biota Contaminants	Trefry, John H. and Robert P. Trocine
cANIMIDA Sediment Contaminants	Trefry, John H. and Robert P. Trocine
ANIMIDA Biota Contaminants	Trefry, John H. and Robert P. Trocine
Oil Industry Physical Oceanography Data	Weingartner, Thomas J., Seth Danielson, Liz Dobbins, Rachel Potter
Reindeer Herder Annual Migration Routes in Nenets Autonomous Okrug, Russian Federation	Yamin-Pasternak, Sveta and Philippe Amstislavski
Study Area in Nenets Autonomous Okrug, Russian Federation	Yamin-Pasternak, Sveta and Philippe Amstislavski
Subsistence Areas in Nenets Autonomous Okrug, Russian Federation	Yamin-Pasternak, Sveta and Philippe Amstislavski
Number of Datasets: 74	

APPENDIX G5. PacMARS Data Archiving, Workflow Status, and MapServer

The Earth Observing Laboratory (EOL) at the National Center for Atmospheric Research (NCAR) was designated as the repository for the PacMARS data and related display and synthesis efforts using a Geographic Information System (MapServer GIS) visualization tool. An online PacMARS Data Archive was developed and implemented for the project team and collaborators http://pacmars.eol.ucar.edu. This website, accessible only to the PacMARS investigators during the period synthesis collaborations, is now open to the broad scientific community. Table G5.1 contains the list of PacMARS datasets (with corresponding author(s)) available through the archive.

The PacMARS metadata team developed recommendations for naming conventions and formatting of data as a step towards standardizing the data and metadata coming into the archive. An online metadata form https://data.eol.ucar.edu/metaarch was introduced at the December 2012 PacMARS Data Workshop for facilitating the collection of metadata and the uploading of data to the archive. A GIS Tiger Team made up project participants and PIs from NCAR/EOL, UMaryland (UMCES-CBL), UTexas, Battelle PNL, SUNY and WHOI worked to develop a common XML format schema for bringing the diverse data into the GIS system. All PIs, their associates and the data managers worked together to develop nearly 160 discrete shapefile layers that are now part of the PacMARS archive along with the data used to build the GIS layers. A listing of these layers is provided in Table G5.1. Geo-locating and overlaying the data upon a map of the PacMARS study area (i.e. MapServer) has proven to be a valuable visualization tool of the online PacMARS Data Archive.

A systematic workflow structure (Fig. B9.1, main text) was developed for data submissions to the PacMARS data archive to facilitate the GIS overlay preparation of the data, with decision criteria based on the extent of metadata and the creation of shapefiles (Section G5.1, Table G5.1). The team implementing this workflow process included members of the EOL data management team and Alynne Bayard of UMCES, along with various PacMARS data providers. When it was discovered that all data providers have use of ArcGIS software, instructions on exporting metadata conforming to the Federal Geographic Data Committee (FGDC) standard from ArcGIS was circulated and used.

Oil industry data collected in the PacMARS study area have also been made available through the PacMARS Data Archive. This is the first time that such an arrangement has occurred. This data exchange was facilitated by members of the PacMARS Advisory Committee with excellent assistance from Axiom Inc. and the Alaskan Ocean Observing System (AOOS). These data have been archived as datasets and are available through the MapServer in multiple layers, organized by type of data.

Long-term stewardship of the data and GIS synthesis overlay products, and access to the data will continue beyond the end of the PacMARS period of performance. The Advanced Cooperative Arctic Data and Information Service (ACADIS) will provide that support for the data and GIS files (http://www.aoncadis.org).

G5.1 Workflow for data submissions to PacMARS Archive and MapServer

The workflow status is designed to allow the data management and Mapserver team to keep up-do-date with all incoming data submissions and their status in the archival workflow. Data sets with an archive ID prefix of "DTS" indicate a data set that is being tracked but has not (yet) been given a project archive identification number. Tabulation of these data sets was undertaken by the EOL data management team. Individual PIs may have other data sets submitted or in process that are not entirely reflected in this table.

It can be assumed that the data provider has one or more data files and zero or more metadata files (as metadata may be contained within the data files).

1. If the data provider needs GIS support, the files (both data and related metadata) are sent to UMCES.
    1.1. When data files are received, UMCES notifies EOL by email and sends received files
        1.1.1. EOL adds this data submission to the Data Tracking System (DTS)
        1.1.2. Contact data provider or consult with PI if there are questions on data or metadata
        1.1.3. Metadata files associated with the dataset are processed by EOL
    1.2. UMCES processes the data files from their current format (e.g. spreadsheet, delimited text, etc.) into a mapserver-compliant format (shapefile)
    1.3. UMCES sends converted data files to EOL
        1.3.1. Layers in shapefiles are added to PacMARS MapServer
        1.3.2. DTS is updated with notes on status of archival process
        1.3.3. Data set loader is assigned
            1.3.3.1. Data files, documentation files, and files for the MapServer are copied to the archive area on disk
            1.3.3.2. Metadata is added to the database
    1.4. Data provider is notified that the data submission has been archived
2. If the data provider is submitting files directly to the PacMARS archive
    2.1. Data provider logins into MetaArch, the online submission tool
        2.1.1. https://data.eol.ucar.edu/metaarch
        2.1.2. data provider requests login if needed (pacmars@eol.ucar.edu)
    2.2. Data provider fills out form to provide metadata for the dataset
    2.3. Data provider submits metadata, creating a dataset in the system
    2.4. Data provider uploads data and documentation files for the dataset
    2.5. PacMARS team is notified automatically by email that a new dataset has been submitted
        2.5.1. EOL adds this data submission to the Data Tracking System (DTS)
        2.5.2. Contact data provider or consult with PI if there are questions on data or metadata
        2.5.3. Layers in GIS files are added to PacMARS MapServer
        2.5.4. DTS is updated with notes on status of archival process
        2.5.5. Data set loader is assigned
            2.5.5.1. Data files, documentation files, and files for the MapServer are copied to the archive area on disk
            2.5.5.2. Metadata is added to the database
    2.6. data provider is notified that the data submission has been archived

UMCES – University of Maryland Center for Environmental Science
EOL – Earth Observing Laboratory at the National Center for Atmospheric Research

Table G5.1 is a list that identifies the GIS layers that have been put into the PacMARS Mapserver, along with those in various stages within the process. There are also comments next to the PIs related to data type and ongoing product development. We also list the datasets in the PacMARS Data Archive, and others that are in process. The PacMARS data archive at the Earth Observing Laboratory at NCAR has archived these data from the following PIs, some only as preliminary datasets, which is why the archive is currently password protected. The final report includes the composite results of GIS map overlays and the interpretation of the resulting findings in relation to the six core themes of this project.

G5.2 Visualization products

EOL implemented the GIS MapServer capabilities used on several recent field deployments to help the PacMARS team visualize and potentially access available marine ecosystem data, products and other value added content. Collaborators from UMCES and EOL staff prepared multiple standardized format shape files geographical information system (GIS). Other work with project collaborators and consultants ensured additional valuable data and information were archived and available to the PI team during the synthesis effort.

A very worthwhile collaboration with the AOOS Project and Axiom, Inc. was undertaken to better integrate the new oil industry data that was made available to the PacMARS Project in fall 2012. Axiom provided support to ingest the industry data into the AOOS archive, generate GIS shapefiles and provide access to them for inclusion in the EOL MapServer. This collaboration with industry is a first for sharing data and fully integrating into the scientific analysis efforts.

Table G5.1 Cross-reference table listing archived ID,, DOI, contact,, data archive status, metadata documentation, and shapefiles to the EOL Mapserver, December 2014. Status: ✓=completed; -=no value.

Archive ID	DOI	Contact	Data Archive Status	Has Doc.	Mapserver Status	Number of Layers
255.001	-	Ashjian	Superceded by 255.060			
255.002	-	Ashjian	Superceded by 255.060			
255.003	-	Grebmeier-Cooper	Superceded by 255.019			
255.004	doi:10.5065/D67H1GMH	Amstislavski	✓	✓	✓	6
255.005	doi:10.5065/D6X63K0J	Blanchard	✓	✓	N/A	-
255.006	doi:10.5065/D6HX19QD	Blanchard	✓	✓	N/A	-
255.007	doi:10.5065/D6M043F3	Blanchard	✓	✓	N/A	-
255.008	doi:10.5065/D6CC0XQQ	Blanchard	✓	✓	N/A	-
255.009	doi:10.5065/D6Z899FB	Blanchard	✓	✓	N/A	-
255.010	doi:10.5065/D66T0JPN	George	✓	✓	N/A	-
255.011	doi:10.5065/D6DB7ZVJ	Okkonen	✓	✓	✓	2
255.012	doi:10.5065/D6KW5D2X	Jay	✓	✓	✓	6
255.013	doi:10.5065/D6K35RP6	Dunton	✓	✓	✓	2
255.014	doi:10.5065/D6KP806T	Bluhm	✓	✓	N/A	-
255.015	doi:10.5065/D6GB223N	Bluhm	✓	✓	✓	1
255.016	doi:10.5065/D6X9289H	Batelle	✓	✓	✓	1
255.017	doi:10.5065/D6QF8QW9	Bluhm	✓	✓	✓	1
255.018	doi:10.5065/D6CJ8BHR	Trefry	✓	✓	✓	4
255.019	-	Grebmeier	Superceded by 255.064, 255.067, 255.072, 255.075, 255.076, and 255.079			
255.020	doi:10.5065/D6PR7T1R	Blanchard	✓	✓	✓	7
255.021	doi:10.5065/D6222RSD	Trefry	✓	✓	✓	4
255.022	doi:10.5065/D65M63R2	Trefry	✓	✓	N/A	-
255.023	doi:10.5065/D6SJ1HM7	Trefry	✓	✓	✓	4
255.024	doi:10.5065/D6C8279S	Trefry	✓	✓	N/A	-
255.025	doi:10.5065/D6PN93NV	Trefry	✓	✓	N/A	-
255.026	doi:10.5065/D6RN35W5	Trefry	✓	✓	N/A	-
255.027	doi:10.5065/D6RF5S2J	Trefry	✓	✓	N/A	-
255.028	doi:10.5065/D6D50K1V	Trefry	✓	✓	N/A	-
255.029	doi:10.5065/D6BC3WJW	Yamin-Pasternak	✓	✓	✓	1
255.030	doi:10.5065/D61Z42F2	Yamin-Pasternak	✓	✓	✓	1
255.031	doi:10.5065/D62V2D54	Yamin-Pasternak	✓	✓	✓	1
255.032	doi:10.5065/D6W66HT9	Amstislavski	✓	✓	✓	4
255.033	doi:10.5065/D6QN64S7	Trefry	✓	✓	N/A	-
255.034	doi:10.5065/D6MP519R	Trefry	✓	✓	N/A	-
255.035	doi:10.5065/D66M34V0	Dunton	✓	✓	✓	1
255.036	doi:10.5065/D63T9F72	Weingartner	✓	✓	✓	2
255.037	doi:10.5065/D61834JZ	Cowee	✓	✓	✓	5
255.038	doi:10.5065/D63R0QX7	Hopcroft	✓	✓	✓	2
255.039	doi:10.5065/D6SF2T7C	Cowee	✓	✓	✓	4
255.040	doi:10.5065/D6G44N92	Cowee	✓	✓	✓	2

Table G5.1 (cont). Cross-reference table listing archived ID files, contact name, archive status, metadata, and shapefiles to the EOL Mapserver, December 2014. Status: **✓=completed; -=no value.**

Archive ID	DOI	Contact	Data Archive Status	Has Doc.	Mapserver Status	Number of Layers
255.041	doi:10.5065/D64Q7S11	Hannay	✓	✓	✓	1
255.042	doi:10.5065/D68S4MXD	Mathis	✓	✓	✓	1
255.043	doi:10.5065/D64T6GCF	Cowee	✓	✓	✓	30
255.044	doi:10.5065/D6J38QK8	Cowee	✓	✓	✓	7
255.045	doi:10.5065/D60Z71B4	Cowee	✓	✓	✓	7
255.046	doi:10.5065/D60863BP	Cowee	✓	✓	✓	3
255.047	doi:10.5065/D69K4880	Whiteaker	✓	✓	N/A	-
255.048	doi:10.5065/D67M05ZX	Bluhm	✓	✓	✓	9
255.049	doi:10.5065/D6125QN1	Cowee	✓	✓	✓	15
255.050	doi:10.5065/D6TH8JQM	Ashjian	✓	✓	N/A	-
255.051	doi:10.5065/D6NV9G87	Ashjian	✓	✓	N/A	-
255.052	doi:10.5065/D6ZS2TJD	Ashjian	✓	✓	✓	2
255.053	-	Ashjian	Merged with 255.052			
255.054	doi:10.5065/D6GT5K7M	Ashjian	✓	✓	✓	2
255.055	-	Ashjian	Merged with 255.054			
255.056	doi:10.5065/D68913WS	Ashjian	✓	✓	✓	2
255.057	-	Ashjian	Merged with 255.056			
255.058	doi:10.5065/D6V69GM1	Ashjian	✓	✓	✓	2
255.059	-	Ashjian	Merged with 255.058			
255.060	doi:10.5065/D69C6VFZ	Ashjian	✓	✓	✓	2
255.061	doi:10.5065/D6QR4V4P	Grebmeier	✓	✓	✓	1
255.062	doi:10.5065/D65T3HHT	Ashjian	✓	✓	N/A	-
255.063	doi:10.5065/D6TD9VC6	Trefrey	✓	✓	N/A	-
255.064	doi:10.5065/D6MW2F69	Grebmeier	✓	✓	✓	4
255.065	doi:10.5065/D6W093Z6	Cooper	✓	✓	N/A	-
255.066	doi:10.5065/D6RB72N6	Cooper	✓	✓	N/A	-
255.067	doi:10.5065/D6F47M47	Grebmeier	✓	✓	✓	1
255.068	doi:10.5065/D63J3B0N	Cooper	✓	✓	N/A	-
255.069	doi:10.5065/D6B27S9X	Cooper	✓	✓	N/A	-
255.070	doi:10.5065/D6V40S7Q	Cooper	✓	✓	N/A	-
255.071	doi:10.5065/D6KK98TJ	Cooper	✓	✓	N/A	-
255.072	doi:10.5065/D600004Q	Grebmeier	✓	✓	✓	1
255.073	doi:10.5065/D6C24TGR	Cooper	✓	✓	N/A	-
255.074	doi:10.5065/D64J0C41	Cooper	✓	✓	N/A	-
255.075	doi:10.5065/D6W9576K	Grebmeier	✓	✓	✓	1
255.076	doi:10.5065/D6H70CVR	Grebmeier	✓	✓	✓	3
255.077	doi:10.5065/D6FT8J2S	Cooper	✓	✓	N/A	-
255.078	doi:10.5065/D60R9MDR	Cooper	✓	✓	N/A	-
255.079	doi:10.5065/D6416V3G	Grebmeier	✓	✓	✓	2
255.080	doi:10.5065/D6MK69ZX	Cooper	✓	✓	N/A	-
255.081	doi:10.5065/D67942QZ	Cooper	✓	✓	N/A	-
255.082	doi:10.5065/D6D21VNK	Cooper	✓	✓	N/A	-

APPENDIX G6. Ecological Network Analysis (ENA)-Robert Ulanowicz)-PacMARS Advisor

Ecological Network Analysis (ENA) is the treatment of networks of "who eats whom and by how much?" The populations comprising and ecosystem and their accompanying resources and sinks are depicted as a collection of boxes that are connected by arrows that represent exchanges of some medium (carbon, energy, nitrogen, etc.) between various pairs of predators and prey. The arrows carry an associated magnitude that quantifies the intensity of that particular exchange. Alternatively, the network can be represented in matrix form where the taxa comprise both the rows and columns of the matrix. The magnitude of a particular exchange becomes the entry into the row of the prey and the column of the predator. Extra rows and columns can be added to the matrix to accommodate exchanges with the external environment.

A suite of mathematical methods for the analysis of ecosystem flow networks representing aquatic systems is described in Ulanowicz (2011). Because the networks can be represented at matrices, one can employ matrix algebra to quantify indirect interactions within the web. Although some pairs of taxa may not directly exchange medium, the substance might flow from one to the other via concatenated pathways. For example, carbon in algal plankton can reach top piscivores via microheterotrophs and filtering forage fishes. All such indirect exchanges can readily be quantified (Szymer and Ulanowicz 1987), and the "indirect diets" (how much any taxon depends on all other taxa) of all species can be presented in tabular form. Often of particular interest are the pathways that contribute to human harvests of ecological resources, i.e., the pyramid upon which human sustenance rests.

Matrix algebra is also useful for describing trophic status within the feeding network. Many predators do not feed at a single integer trophic level. A fish predator might ingest benthic heterotrophs as well as a suite of forage fishes. Each pathway from food source to final recipient can be weighted according to the amount of medium that flows along it and the pathways averaged to obtain the effective trophic level at which the predator feeds (Levine 1980). Thus, striped bass in Chesapeake Bay are estimated to feed at an effective trophic level of 3.87 Alternatively, the throughput of any taxon can be apportioned according to how much of it flows along integer pathways of various lengths. (How much reaches the predator along all pathways of length 2, of length 3, length 4, etc.?) The throughflows of the various taxa in a web can therefore be apportioned to virtual integer trophic levels, resulting in an equivalent trophic chain (or pyramid) (Ulanowicz 1995).

Controls within ecosystems are thought to be associated with cycles of material flows that are imbedded within flow networks. Ulanowicz (1983) has developed an algorithm for identifying all simple cycles in a flow network and abstracting them from the supporting network of dissipative flows. That is, a trophic flow network usually can be decomposed into two separate networks, the first of which consists of only closed cycles and the other is an acyclic tree of throughflows and dissipations. The composite network of cycles often reveals features of how the system is operating (See Fig. 11 in Baird & Ulanowicz 1989).

Finally, it is possible to quantify the overall status of the network using indices garnered from information theory (Ulanowicz and Norden 1990). Networks in general are composites of constraint and flexibility. The exact proportions of these mutually-exclusive traits can be calculated. Of particular interest is how sensitive the index of constraint is to the stock of each compartment or to each flow in the network. These sensitivities point out the bottlenecks and vulnerabilities within the given system (Ulanowicz and Baird 1999).

Unlike simulation modeling, ENA does not provide the user with exact quantitative predictions. Predictions of ecosystem behaviors via mechanical simulations, however, have not proven very successful

(Platt et al. 1981). Alternatively, ENA mines the available data for hidden features and provides purportedly more reliable inferences useful for qualitative prognostication.

A number of algorithms are currently available to help the investigator construct quantified ecosystem networks from data on species abundances, physiological rates and putative diets (Christensen & Pauly 1992, Ulanowicz and Scharler 2007) It is to be hoped that PacMARS will create a system of data storage and retrieval that will greatly facilitate such estimation of quantitative ecosystem networks of Arctic habitats.

Currently, a subset of PacMARS investigators is estimating separate networks for the Southern Chukchi and Northern Chukchi areas. The intention is to use the respective networks to investigate how the more northern areas might change under global warming. The emphasis in the comparison will not be limited to changes in taxa and their respective densities, but also will forecast how the actual kinetics are likely to change – how the indirect subsidies might respond to warmer temps, what the impact might be on trophic structure, what changes on resource recycling might ensue and how whole indices of organization and flexibility are likely to respond. The estimation of the networks is 90% complete. Analysis and interpretation of results is in progress. The investigators are attempting a new strategy for network estimation by using allometric calculations to ensure consistency among the physiological parameters required for the estimation, especially as regards how these may change with altered temperatures."

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APPENDIX G7. List of Key Abbreviations

Abbreviation	Institution / Agency
ABR	ABR, Inc. Environmental Research and Services
ADF&G	Alaska Department of Fish & Game
AFMP	Alaska Fisheries Management Plan
AFSC	Alaska Fisheries Science Center (NOAA)
AKMAP	Alaska Monitoring and Assessment Program
AON	Arctic Observing Network
AOOS	Alaska Ocean Observing System
ARC	Arctic Research Commission
AMAP	Arctic Monitoring Assessment Program
ArcEIS	Arctic EIS
BOEM	Bureau of Ocean Energy Management
BOWFEST	Bowhead Whale Feeding Ecology Study
BSSN	Bering Sea Sub-Network
cANIMIDA	Continuation of the Arctic Nearshore Impact Monitoring in the Development Area
C3O	Canada's Three Oceans
CBL	Chesapeake Biological Laboratory (UMCES)
CCGS	Canadian Coast Guard Ship
CHAOZ	Chukchi Acoustics, Oceanography and Zooplankton Study
CHINARE	Chinese National Arctic Research Expedition
COMIDA-CAB	Chukchi Sea Offshore Monitoring in Drilling Area – Chemical and Benthos
COMIDA-Hanna Shoal	Chukchi Sea Offshore Monitoring in Drilling Area – Hanna Shoal
CSESP	Chukchi Sea Environmental Studies Program
DBO	Distributed Biological Observatory
DFO	Department of Fisheries and Oceans, Canada
DPP	Division of Polar Programs
EcoFOCI	Ecosystems and Fisheries-Oceanography Coordinated Investigations
EOL	Earth Observing Laboratory
GRENE	Japanese Arctic Climate Change Research Program
IARPC	Interagency Arctic Research and Policy Committee
IASC	International Arctic Science Committee
ICESCAPE	Impacts of Climate on the Eco-Systems and Chemistry of the Arctic Pacific Environment
JAMSTEC	Japan Agency for Marine-Earth Science and Technology
KOPRI	Korean Polar Research Institute
MWG	Marine Working Group
NAMMCO	North Atlantic Marine Mammal Commission
NASA	National Aeronautics and Space Administration
NCAR	National Center for Atmospheric Research
NMML	National Marine Mammal Laboratory (NOAA)
NOAA	National Oceanic and Atmospheric Administration
NPRB	North Pacific Research Board
NSF	National Science Foundation
NSSI	North Slope Science Initiative
PAG	Pacific Arctic Group

PMEL	Pacific Marine Environmental Laboratory
RUSALCA	Russian-American Long-term Census of the Arctic
R/V	Research Vessel
SBI	Western Arctic Shelf-Basin Interactions project
SCAR	Scientific Committee for Antarctic Research
SIWO	Sea Ice for Walrus Outlook
SNACS	Study of Northern Arctic Coastal Systems
UAF	University of Alaska Fairbanks
UMCES	University of Maryland Center for Environmental Science
USCG	United States Coast Guard
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey
UW	University of Washington
WHOI	Woods Hole Oceanographic Institution

APPENDIX G8. Hub Report Community Meetings during February-March 2013.

Pacific Marine Arctic Regional Synthesis (PacMARS)

Community Meetings during February-March 2013

Citation: Grebmeier, J.M. (editor). 2014. Pacific Marine Arctic Regional Synthesis (PacMARS) Community Meetings during February-March 2013. PacMARS report, 30 pp.

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1. Introduction

The Pacific Marine Arctic Regional Synthesis (PacMARS) is a $1.45 million research synthesis effort funded by Shell Exploration and Production and ConocoPhillips but administered and managed by North Pacific Marine Research Institute through the North Pacific Research Board, and with oversight from the National Science Foundation Office of Polar Programs. This synthesis is assembling up-to-date written documentation that contributes to understanding the Pacific-influenced continental shelf ecosystem of the Arctic Ocean. This study area extends from Saint Lawrence Island in the Bering Sea through Bering Strait into the Chukchi and Beaufort Seas (Figure 1). The overarching objective is to compile the best available knowledge from local communities and peer-reviewed social and natural sciences, as well as less readily available knowledge sources A key objective of the project is to identify future scientific needs and research gaps in the region. The expectation is that identification of such needs will assist stakeholders including agencies that support research for understanding this important ecosystem and its vulnerabilities.

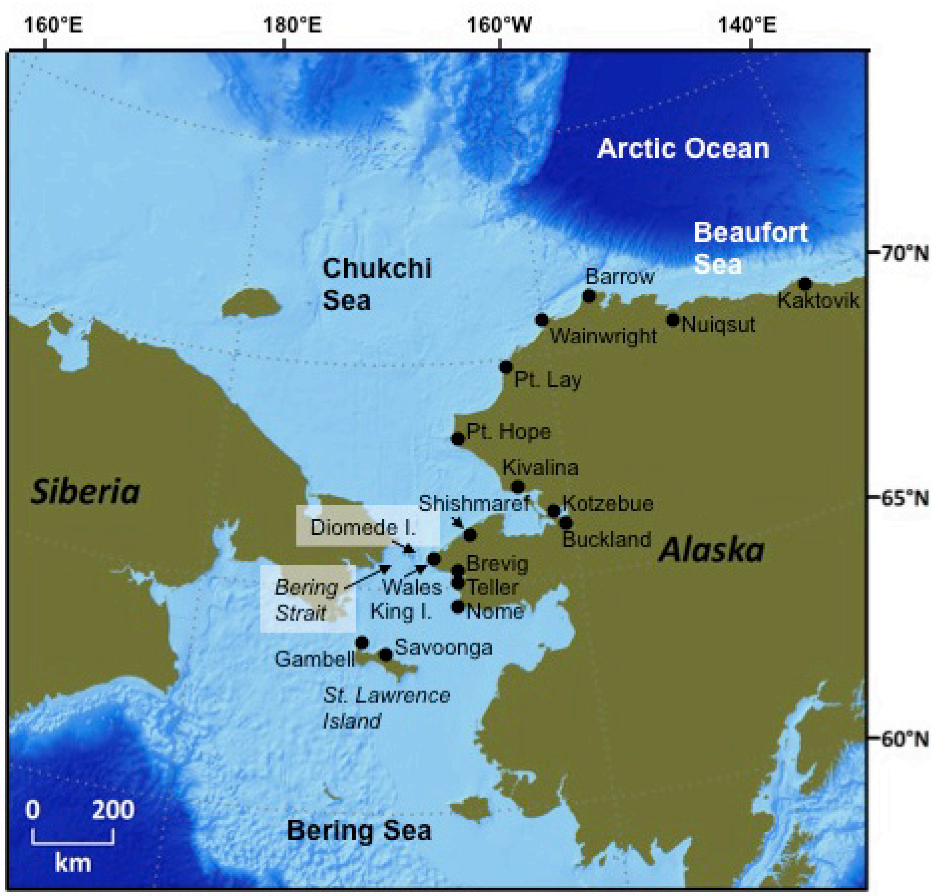

Figure 1. The region of the PacMARS synthesis effort in the Pacific Arctic.

As seasonal sea ice continues to decline in the Arctic, having reached a record minimum in 2012, oil and gas exploration and other industrial maritime traffic are increasing. Increasing ship traffic through Bering Strait has been occurring as part of the Northern Sea Route along the north coast of

Russia, which is beginning to provide a practical ice-free route between Asia and Europe with reduced shipping costs. The Northwest Passage (through the Canadian Arctic) has also become ice-free several times in recent summers, a significant change though the growth of ship traffic along the Northwest Passage has been less than the Northern Sea Route. In addition, all of the Arctic Ocean countries, including Russia, the United States, Canada, Norway and Denmark (Greenland) are exploring the limits of their arctic continental shelves in order to advance claims under the Law of the Sea Treaty.

Climate warming is occurring in the Arctic at a faster pace than at lower latitudes. In addition to shifts in seasonal sea ice coverage, socio-economic changes are also underway in the Arctic. For example, availability and accessibility of marine resources necessary for subsistence hunting in the Arctic has become less predictable, which stems from environmental variability. Many organisms, from plankton to top predators, will show changes in productivity, timing of migrations and foraging patterns as organisms adjust to shifting sea ice and seawater temperatures. Both wildlife populations and human communities will need to adapt to these changing conditions. Increased industrial development and transportation as more open waters occur seasonally will likely impact the ecosystem and the people that utilize those resources.

The PacMARS project has 6 research themes that serve as foci for the PacMARS synthesis effort:

1. Ice Cover (primary production relationships, currents, winds, bathymetry)
2. Phenology of Biological Production Cycles in Relation to Physical Environment
3. Benthic-Pelagic Coupling in Relation to Physical-Chemical Environment
4. Current State of Lower Trophic Prey-Base and Higher Trophic Feeding Hot Spots
5. Subsistence Lifestyles in Times of Climate Change
6. Chemical Contaminants in Sediment and Biota

As part of the overall goals of PacMARS and specifically addressing research needs under Theme 5: *Subsistence Lifestyles in Times of Climate Change*, the PacMARS team conducted five regional Alaskan community meetings on St. Lawrence Island, and in Barrow, Kotzebue and Nome (Table 1). The meetings provided a forum for feedback on research needs as they are perceived by local communities as well as for ecological insights from subsistence hunters specifically and local residents in general. Two of the community meetings (Gambell and Savoonga) were conducted as

Table 1. Date, location and communities served at PacMARS regional community meetings**.**

Date	Meeting Location	Communities Represented
January 28, 2013	Savoonga	Savoonga
January 29, 2013	Gambell	Gambell
February 11, 2013	Barrow	Barrow, Wainwright, Point Lay, Nuiqsut, Kaktovik
February 22, 2013	Kotzebue	Kotzebue, Point Hope (representative unable to attend), Buckland, Kivalina
February 25, 2013	Nome	Nome, Diomede, Wales (no representative attended), King Island (no representative attended) Brevig Mission, Teller, Shishmaref

formal open community style meetings. The other meetings were "hub" style meetings with representatives selected by the Indian Reorganization Act (IRA) Councils that serve as tribal governments for each village represented. Representatives from Wales, King Island, and Point Hope were unable to attend. Comments contributed at each village meeting contained in this report have been edited for clarity, but represent the opinions expressed at each meeting by participants.

The PacMARS community meeting objectives included:

- To provide an explanation of the PacMARS effort
- To give updates on research in the respective areas
- To discuss marine issues important to the communities including gaps for future study
- To discuss useful ways of communicating science results
- To identify good examples of regional knowledge and western science working together

The following report includes comments on marine issues and suggestions for future research needs and communications in Section 2. A composite summary of consensus topics that were heard at all of the community meetings is provided in Section 3. Appendix A lists all the participants for each community meeting and their affiliations.

2. Regional Community Meeting Summaries

Five Alaskan regional community meetings were held: two in the villages of Savoonga and Gambell on St. Lawrence Island and three “hub” meetings that included representatives from surrounding villages that met in the larger communities of Barrow, Kotzebue and Nome for group discussions. The following section provides summaries of each of these community meetings.

2a. Savoonga Community Meeting, St. Lawrence Island, AK (January 28, 2013)

Attendees:

David Akeya, James Akeya, Tom Akeya, Robert Annogiyuk (Native Village of Savoonga), Lee Cooper [University of Maryland Center for Environmental Science/Chesapeake Biological Laboratory (UMCES/CBL)], Arnold Gologregen, Jackie Grebmeier (UMCES/CBL), Dylan Iya, Hiram Kiyuthlook, Mitchell Kiyuthlook, Clinton Kogassagan, Chester Noongwook, Thor Noongwook (Native Village of Savoonga), Wilson Okoomealingok, Perry Pungowiyi, Bryan Rookok Jr., Elmer Rookok, Paul Rookok Sr. (Savoonga IRA Council), Gay Sheffield ([University of Alaska Fairbanks (UAF)], Sveta Yamin-Pasternak (UAF)

Brief Narrative:

There were 20 attendees at the Savoonga community meeting, including four PacMARS co-PIs (Cooper, Grebmeier, Sheffield, Yamin-Pasternak). Members of the community represented personal interests, the Savoonga IRA Council, and the Native Village of Savoonga. The meeting began with an introduction of participants. After a brief introduction by Gay Sheffield, Lee Cooper and Jackie Grebmeier provided an overview on PacMARS and regional science. Sveta Yamin-Pasternak provided a presentation on science, language and local foods.

During the meeting, attendees identified the marine issues of concern via comments and questions, and provided suggestions as follows:

Marine issues of concern:

- Negative impacts from increased ship traffic, especially noise and pollution events, on the essential marine subsistence resources.
- Ship noise and potential acoustic deflection due to the noise affecting the walrus’s ability to access their feeding grounds, areas where they would normally congregate, etc.
- Regionally specific information and/or issues that may be useful but are not considered for study (i.e. different sized walruses on different sides of the island).
- Connectivity between walrus populations around St. Lawrence Island in the northern Bering Sea and those around the North Slope Borough in the Chukchi Sea.

- What will be/are the effects of warmer water and less sea ice on the ecosystem?
- Comments were made about the health of southern walrus populations, which are skinnier than other walrus populations.
- Warmer water is allowing gray whales to move further north, same with dominant amphipods, thus both food/diet changes are occurring.
- People are also observing a northward movement of humpback whales.
- People would like to see the Sea Ice Walrus Outlook (SIWO) project be year-round.
- What are the impacts of trawling on the ecosystem? Will trawling cause benthic habitat degradation and subsequent effects on benthic foragers that are essential subsistence species (ex. walruses, bearded seals, eider ducks)?
- Shipping lanes are opening up, with increases in annual ship traffic. Related threats to marine mammals could include oil spills, industrial ship noise impacts, deflection of game from an area or their traditional migratory patterns, temperature changes, disruptions to wildlife physically from ships, and pollution.
- There is an issue of incomplete information about ship traffic and vessel whereabouts – it was estimated that only 10% of ships report to the Savoonga office, which is funded by Shell through the Bering Straits Native Corporation.
- Insufficient translation or interpretation of scientific research – for example, what is meant by synthesis?
- Evaluation of oil impacts on wildlife requires looking at whole migration pathways.
- What are the impacts to the marine waters from Red Dog Mine north of Bering Strait?
- Concerns that certain mammal species (i.e. whales) are getting too much focus from certain funders (ex. Shell Oil) – recommend that the scientists should study the "whole nine yards" – a comprehensive ecosystem approach is needed.
- Ship traffic: concerns about deflection of game/human safety, food security/health, food safety, human impact/danger to boaters/pollution, etc., physical safety issues for wildlife and humans, noise, spills /pollution, disease introduction.
- There is still uncertainty on cause of the Northern Alaskan Pinniped UME (Unusual Mortality Event).
- Lack of monitoring for Fukushima radiation in air, water, or wildlife.

Community suggestions:

- Study the still undetermined disease that is affecting the seals/walrus.
- Need to monitor for changes in the migratory patterns/timing of marine mammals, fish, and seabirds.
- Need to increase the knowledge regarding procedures, protocols, and science to mitigate effects and/or the effects of shipping to the Bering Strait wildlife and ecosystem, especially effects from pollution, noise, etc.
- Need to provide information about how to meet the nutritional, cultural, and economic needs of the peoples if animals move (prey change) or choose to move away, e.g. due to ship noise.
- People would like the scientific information to be presented in a way that the layperson could understand, including defining what a synthesis is.
- Translation/integration of local knowledge to science should be addressed.
- One Elder considers himself a predator as part of the island's ecosystem, therefore what he does through his subsistence lifestyle benefits and maintains the system.
- Need for integrated community participation in research via internships, shipboard research, and/or community involvement.
- Need better understanding regarding human use/needs on the Russian side of the Strait.
- Provide regular participatory public updates.
- Get Alaska Native youth/students involved regionally/locally.
- Study the ecosystem and wildlife but there is a need to relate results to public health and food security /food safety issues.

2b. Gambell Community Meeting, St. Lawrence Island, AK (January 29, 2013)

Attendees:

Paul Apangalook, Preston Apangalook, Edmond Apassingok, Melvin T. Apassingok, Mr. Apatiki, Iver Campbell, Lee Cooper [University of Maryland Center for Environmental Science/ Chesapeake Biological Laboratory (UMCES/CBL)], Jackie Grebmeier (UMCES/CBL), Mark Nupowhotuk, Miriam Oseuk, Gay Sheffield [University of Alaska Fairbanks (UAF)], Eddie Ungott, and Sveta Yamin-Pasternak (UAF)

Brief Narrative:

The meeting opened at 9 AM. There were 12 attendees at the Gambell community meeting. After an introduction by PI Gay Sheffield on who we were and what the objectives were for both NPRB and PacMARS, the PacMARS PIs Lee Cooper, Jackie Grebmeier, and Sveta Yamin-Pasternak explained the PacMARS program from their disciplinary perspective and asked for input on what the key marine issues of concern were for the community. Community members asked for a poster regarding PacMARS and its results using terminology better suited for non-western scientists.

During the meeting, attendees identified the marine issues of concern via comments and questions, and provided suggestions as follows:

Marine issues of concern:

- Invasive species – what are they, are they coming here, and what will they do?
- Observing northward shifts of some species.
- Ice is important for determining where walrus drift, so changes in wind patterns and ice drift have impacts on walrus locations for subsistence hunting.
- Are scientists missing timing or spatial aspects of the sampling period?
- Study other animals that have human health/food security/ecosystem health potential than those that have the main focus. For example, the study of compound tunicates and beach greens that are consumed by people and that have their own role in the ecosystem were suggested.
- Disparities between existing regulatory framework within the context of ecosystem processes are an issue. For example, people are a part of the ecosystem in a predatory role – it should not be considered wanton waste to leave some animal parts behind after hunting – we share with human beings and we share with the other animals too.
- Input is needed from the elders to determine priorities.

- Study the present toxicity/contaminant levels of marine subsistence foods and relate that to public health and food safety issues.

- Lesions seen for seals and questions arose as to why is there this sickness? High priority to find the cause of the Northern Alaskan Pinniped UME.

- If populations of subsistence foods change in numbers and/or become too toxic to eat, what will be the alternative food source for our people?

- Study the impact/destructive forces on communities if the marine ecosystem is to be/will be affected by changes.

- The Bering Sea is said to be productive but the huge commercial fishing industry is fishing out the south and heading to the north. How will regional impacts be addressed? What will happen here near the Island?

- Local coastal monitoring of fish, invertebrates, and large game happens on a daily basis as the subsistence community observes the health of the organisms throughout the ecosystem – integrate that expertise in scientific studies.

- Where/how does our traditional knowledge fit with the future?

- The human use of shared marine resources is with our Russian neighbors too. Scientists need to study both sides of the Strait as well as the two sides of the oceans up north.

- Study where the toxic marine dump sites are in the ocean.

- Study the effects of melting ice on the changing environment.

- Preserving/acknowledging the critical habitat (subsistence) marine seascape of St. Lawrence I. to commercial trawl fisheries concerns.

- Commercial fishing impacts on the marine ecosystem (benthic and mid-water).

- Why are we seeing changes in different bird populations?

- Levels of contaminants in the marine environment are of concern for health as well as food safety/food security concerns.

- What are the impacts of real and perceived toxicity of subsistence foods?

- Observations mentioned of fall storms that wash up amphipods on the island shores.

- Ship traffic impacts:

- Acoustic deflections
- Human safety
- Food Security
- Physical safety issues for wildlife
- Physical safety issues for humans
- Spill events
- Invasive species
- Pollution/contaminants

Community suggestions:

- Contact the elders individually or through meetings to better understand their views on the the types of marine research that are needed in the future.

- Communicate results and ideas graphically/visually. Use visual types of communication.

- Document the disconnect between the role of people in the subsistence use/cultural practices framework and regulatory obligations/framework.

- Ground truth project results with community input. The government can have a head start for the problem/study since there is local knowledge available in coastal communities.

- Focusing just on zooplankton is not enough; instead there is a need for a broad scale approach to understanding the whole ecosystem.

- Use projects like the Sea Ice for Walrus Outlook (SIWO), Bering Sea Sub-Network (BSSN), etc. to better connect with the communities.

- Appreciate the economic value of traditional knowledge.

- How will you study the industrial impacts on marine foods – both the health of that food and the availability/accessibility of the marine foods (i.e. invertebrates, fish, mammals, birds)?

- Study the seabird population changes – the opinion was expressed that this marine resource has been overlooked.

- Involve Native coastal communities when scientists are at the proposal writing stage.

- The St. Lawrence Island marine habitat is the breeding/feeding grounds for all marine animals in the region – these waters need to be protected.

- Have face-to-face meetings to provide results of research/news in the area. Use multiple media sources including regional newspaper, radio, hub outreach/education outlets.

- Avoid conflicting communications regarding subsistence marine resources and contamination, e.g. different viewpoints regarding contaminant levels in bowheads, e.g. Alaska Community Action on Toxics versus North Slope Borough Department of Wildlife Management.

- Need to conduct similar studies on subsistence marine resources from Saint Lawrence Island to Barrow as similar measurements will be easier to compare/contrast over time and space.

- Concern about when and how Fukushima origin radioisotopes will reach Saint Lawrence Island.

- Concerns are great regarding the risks of oil spills on seals (and other marine wildlife) and the logistical challenges of spill response with future increases in industrial development and shipping.

- The ecosystem is changing at the same time commercial fishing, oil industry, and large vessel traffic is increasing.

- Ship noise and more Russian trawlers in the region are concerns.

- Concern for increased vessel traffic through the region and the potential for pollution on the marine ecosystem, subsistence wildlife populations, and human health risks.

Of note:

- Spiny king crab (Hanasaki; *Paralithodes brevipes*) are increasing in the area with many more caught during 2012 than before.

- Walrus hunting occurring further north than before; what does this observation say about any changes in walrus feeding and breeding areas?

- *Opilio* sp. of crab can wash up in numbers (thousands) at a time.

- Eider ducks have declined dramatically, as has the oldsquaw (long-tailed) duck.

- Look to the past before studying the future (supporting retrospective studies).

- Things are changing – and people are having to adjust.

2c. Barrow, AK Community Meeting (February 11, 2013)

Attendees:

Billy Adams [North Slope Borough/Dept. of Wildlife Management (NSB/DWM)], Lily Anniskett (Native Village of Point Lay), Carin Ashjian (Woods Hole Oceanographic Institution), Danielle Dickson [North Pacific Research Board (NPRB)], Craig George (NSB/DWM), Lee Kayotuk (Native Village of Kaktovik), John Nicholls (Native Village of Nuiqsut), Steve Okkonen [University of Alaska Fairbanks (UAF)], Hugh Olemaun (Barrow), Billy Blair Patkotak Jr. (Native Village of Wainwright), Gay Sheffield (UAF), Raphaela Stimmelmayr (NSB/DWM), Ellen Tyler [Alaska Ocean Observing System (AOOS)], Sveta Yamin-Pasternak (UAF)

Brief Narrative:

The meeting opened at ~9:15 AM. After a brief introduction by PI Gay Sheffield, Billy Adams offered an invocation. There were several presentations by the PacMARS team (Ashjian, Sheffield, Yamin-Pasternak), Danielle Dickson (NPRB), and Ellen Tyler (AOOS). The format was informal, with all participants welcome to, and frequently, offering suggestions and observations regarding important marine scientific questions and effective and novel means of communication of science activities and results to local communities. There was a lunch break from 11:45 AM-1:00 PM in the Ilisagvik College Cafeteria followed by resumption of presentations and discussion. The meeting concluded at 4:45 PM.

During the meeting, attendees identified the marine issues of concern via comments and questions, and provided suggestions as follows:

Marine issues of concern:

- Arctic marine mammals are known to have medicinal value. What are these natural products? Examples: beluga whales, seal oil is effective in killing bacteria, seal oil is used for several medicinal purposes; sea turtles in the Caribbean also have medicinal properties. Research is needed on the medicinal qualities of marine mammal oil and other marine mammal products.

- Research why Native foods keep you less hungry longer than processed “white man” foods.

- What natural products with medicinal value are present in the Arctic marine environment?

- Why are bowhead whales not seen close to shore near Barrow in recent years as they were frequently in the past? Is the increasing scientific and commercial marine activity influencing the whales’ behavior so they do not approach the shore?

- What are/will be the impacts of the oil companies 5-10 years from now? There is a need to monitor the impacts of the oil companies long-term, and not just for a few years.

- Long-term studies of the ecosystems are necessary to detect if impacts exist over time.

- What are the impacts of noise from all of the ongoing and future activities associated with oil/gas development, shipping, as well as research on animal behavior and other aspects of the ecosystem?

- Is there a physiological impact of industrial sound on marine animals such as mammals and plankton? For example, seismic noise impacts on different types of organisms..

- What would be the impact of a spill of a contaminant such as oil or drilling muds on the ecosystem and on the upper trophic level predators that serve as subsistence for local communities?

- What are the impacts of vessel discharges, either planned or accidental, on the marine ecosystem?

- What are the impacts on subsistence hunting of regulatory actions by government agencies (e.g., duck hunting seasons that may/may not coincide with availability of ducks)? How can these two competing interests be reconciled?

- Are there ongoing changes in migration timing and routes of important upper trophic level animals (birds, fish, and mammals) that are associated with climate change or with anthropogenic activities? What will the impact of these changes be on subsistence hunting of these resources?

- What starts the bowhead whale fall migration from Canada to the Bering Sea? Can the timing of this migration be predicted based on environmental or whale observations?

- How can communities retain their cultural identity, including utilization of traditional foods by the young members of the community?

- What is the impact of ongoing environmental changes on weather and local infrastructure? For example, concern was expressed about the integrity of ice cellars the shoreline and critical structures along the coast (e.g., roads and buildings).

- How much additional activity associated with research and other activities can communities and local ecosystems tolerate?
    - For example, it was stated that there is a negative impact of all the multiple research projects on the Southern Beaufort Sea population of polar bears.
    - Also, it is desirable for research to address local stakeholder needs.

- Research questions should be trans-boundary (e.g., across international boundaries) and Pan-Arctic (e.g., are there connections between the Beaufort and the eastern Arctic such as near Greenland?).

- What might the effects of ocean acidification and other environmental change mediated physiological responses be on populations of marine organisms?

- Why do walrus haul out at Point Lay vs. some other location that is closer to Hanna Shoal? (It might be learned behavior. "They hauled out there once and remembered the place").

- What will be the availability and health of subsistence animals? Availability includes both abundance and migration behavior (timing and paths).

- What was the cause of the 2011 Northern Alaskan Pinniped Unusual Mortality Event (UME) seal disease?

- What is the impact of climate change on the abundance, composition (type), and availability of marine species? For example, fish species are showing an increase in diversity and there are songbirds seen on the North Slope that were not seen previously.

- What is the impact of climate change on polar bear populations and behavior? For example, polar bears near Kaktovik cannot get food because of the retreat of summer sea ice so they are near town, hungry, and having an impact on the activities of the local community.

- What would be the impacts of increased commercial activities such as commercial fishing, shipping, and oil exploration on bowheads? For example, commercial fishing might lead to entanglements and shipping could result in collisions between ships and whales (or ships and whalers).

- What might be the impact of contaminants or substances in air emissions on the marine ecosystem?

- What might be the impact of hydraulic fracturing (for natural gas) on water in rivers, fish in rivers, and discharge into the ocean?

- Coastal communities concerns include:
    - Noise from offshore industry and associated vessels
    - Oil spill/pollution effects
    - Current regulatory constraints vs. subsistence foods/needs
    - Changes in the weather impacting subsistence – i.e. melting ice cellars
    - Coastal erosion destroying communities
    - Does the oil industry really understand sea ice – need to research ice movements, etc. The behavior of oil under sea ice needs to be studied in a controlled environment.

- Research the cumulative impact on the few "popular" species that are being continually researched. e.g. Polar bears.

- Research the radiation concerns resulting from the Fukushima power plant disaster. Comprehensive research on the presence of contaminants from this source and/or impacts and including the animals on the seafloor.

- Ocean acidification is a concern – we need more research on its effects.

- Drilling muds – how will they affect wildlife/foods that are used in coastal subsistence communities food?

- Industrial shipping – unregulated water/sewage emissions – what are/will be the effects?

- Commercial fishery impacts on arctic species – what are the physical effects?

- Air emissions from industrial ship traffic, coastal communities, and drill platforms, etc. – need to understand the effects.

Suggested ways to more effectively communicate:

- Engage tribal governments in consultation. (NPRB wants to engage in such consultations regardless of whether there is a requirement by other funding agencies to do so).

- Need subsistence Advisor to coordinate research activities so as to not interfere with subsistence activities. Need to have a subsistence advisory person to communicate future studies in order to lessen conflicts with subsistence activities – would need to be regionally specific as each coastal region/community has different subsistence activities/timing/focus.

- Involve youth in research.

- Have community meetings with scientists to communicate planned research activities.

- Scientists should return to communities to communicate findings.

- Outreach and education are needed.

- Cultural education for research scientists and others.
    - A course, preferably taught in person, that would teach people about the cultures and practices of the communities in which they will be working. As an example, it would be helpful for scientists to understand in what seasons the local communities hunt for the different subsistence animals. The "students" should include teachers, researchers, oil field workers, and law enforcement, anyone who will be working in a community. There are regional differences in culture that will require different classes for the different regions.

- Communities need tangible products to document a range of information including state of the ecosystem, outcomes of meetings such as this one, outcomes of the NPRB study, and the importance of subsistence resources. (The reports from these community meetings will be available to the communities. The reports from the PacMARS project also will be available to the communities).

- When in Barrow, arrange for a two-hour radio show on KBRW. Make sure to advertise the show to the communities that can receive the KBRW broadcast. Make sure that the title of the show reflects the content so people can decide whether or not to listen.

- Establish a really good coast-wide hunter reporting network. This would facilitate coordination between community observations/knowledge and scientific research. An excellent example of such coordination is the reporting of the Northern Alaskan Pinniped UME seal wasting disease in 2011 in which the first reports came from the seal hunters.

- Involve students. There are some good examples, such as the US Fish and Wildlife "Ambassador Students" program. "Follow the samples" would have students go to laboratories at the home institutions of scientists to see how samples are analyzed. Students might participate on research vessels/boats.

- Engage subsistence hunter(s) in collection of data.

- For meetings in villages at which you wish to communicate upcoming work, send the information to the village ahead of time and use comment forms to solicit input (Native Village Process).

- Work with the Native Village Tribal Government and other local entities to set up meetings, i.e. City Offices and Native Corporations. It was noted that villages vary in the extent to which of these entities work in a unified way.

- Engage the Fish and Game Management Committee or equivalent for each village to help communicate plans and results.

- Hold regional meetings, such as this one that are "hub" meetings, so that representatives from the different communities can communicate with each other as well as with the scientists and agency representatives.

- Have a presence at the Alaska Federation of Natives annual meeting. This would be a great thing for the NPRB to do. Piggyback on other forums.

- Currently there is not enough reporting to the coastal communities on Arctic research – by those whose projects are proposed and/or ongoing.

Additional comments:

- Currently not enough cultural training to researchers that are coming into a coastal region/community with respect to subsistence, regional sensitivities, timing, uses.

- Need to get the information/results back to the communities.

- Invite one representative for a meeting to hear the results of research (i.e. City Office, Tribal Council, and Native Corporation) – for EACH village where the research was undertaken.

- Coordinate with other agencies / forums i.e. Rural Advisory Committees, State and federal agencies, as well as University outlets/programs.

2d. Kotzebue, AK Community Meeting (February 22, 2013)

Attendees:

Earnest Barger Sr. (Native Village of Buckland), Lee Cooper [University of Maryland Center for Environmental Science/Chesapeake Biological Laboratory (UMCES/CBL)], Danielle Dickson [North Pacific Research Board (NPRB)], Jackie Grebmeier (UMCES/CBL), Richard Sage (Native Village of Kivalina), Damian Satterthwaite-Phillips [Northwest Arctic Borough (NAB)], Gay Sheffield [University of Alaska Fairbanks (UAF)], Zach Stevenson (NAB), Ellen Tyler [Alaska Ocean Observing System (AOOS)], Sveta Yamin-Pasternak (UAF). The Mayor of the NAB, Reggie Joule and staff from the NAB planning department attended the end of the meeting.

Brief Narrative:

The meeting opened at ~9:00 AM at the Northwest Heritage Center. Gay Sheffield provided an introduction to the project as well as the focus and goals of the meeting. Several presentations by the PacMARS team (Cooper, Grebmeier, Sheffield, Yamin-Pasternak), Danielle Dickson from NPRB, and Ellen Tyler from AOOS followed. The format was informal, with all participants frequently offering suggestions and observations regarding important marine scientific questions and effective and novel means of communication of science activities and results to local communities. There was a lunch break from 11:45 AM-1:00 PM and lunch was provided followed by resumption of presentations and discussion. NAB Mayor Reggie Joule, in the company of several staff members, provided an informal presentation that continued until the end of the meeting at 5:15 PM.

During the meeting, attendees identified the marine issues of concern via comments and questions, and provided suggestions as follows:

Marine issues of concern

- Lack of communication - communities do not understand the relevance of the research projects in their region.
- Translation issues with Native language to English as well as scientific English to layman English.
- Food security is a consistent issue for people in subsistence-dependent communities.
- Erosion of the coastline is a concern to communities and their cultural, physical, and economic survival as they are directly part of the marine environment.
- How do we balance concerns about lifestyle, social policy and vision, while allowing for adaptation?
- There are participatory processes for land issues – what is the participatory public process for marine/marine ecosystem/research/communication issues? Are there any?

- Concern about location of shipping lanes, oil development, future fisheries, roads connecting communities, and fast moving industrial developments in a time of environmental change.

- Offshore and onshore mining are concerns. Onshore mining that affect watersheds will have an eventual effect on the marine ecosystem through rivers and runoff.

- What is the participatory process that allows coastal communities and Alaskans to have a voice in the NANA region regarding marine issues?

- What effect does increased warm water coming northward along the Alaskan coast have as on food webs?

- How will results of hub meeting be provided back to the communities?

- Increase in large vessel traffic is a large concern – communities are concerned for the sea mammals and the prey it takes to sustain those animals. Will the ships scare off the game from their traditional migratory routes? Affect the timing of their movements? Affect the prey the marine mammals need to survive?

- Decrease in the thickness and timing of the sea ice is a concern – changes will affect the food chain – that includes humans. The sea ice thickness and timing is changing.

- Have the ocean currents changed – and if so, how? Where are the ocean fronts and are they changing, moving, or have they already moved?

- The ocean currents and the weather patterns and any changes to either of these are important to all coastal communities.

- Is fresh water runoff affecting the ocean waters – is it changing the currents and/or the types of seawater?

- What were the ancient currents like and how did they affect the marine ecosystem?

- What are the effects of research on our essential marine resources?

- What are the levels of contaminants throughout the marine ecosystem – the foods, the waters, etc.?

- There are concerns as to the impacts on marine resources, habitats, and the ecosystem from large-scale commercial fisheries moving north into the Northwest Arctic region.

- Concerns regarding regional allocation of resources vs. commercial interests. "Rich people will come and take what we have". There is a real concern for the Urban/Rural divide in resource allocation, political voice, etc. with respect to marine resources.

- Increased marine transportation, offshore development, and commercial fisheries – all are marine concerns to the region due to how they will affect the marine environment, resources, and health of the peoples.

- Russia is a great concern due to our current lack of communications associated with oil spill response, wildlife events, etc.

- Sovereignty ending at the beach is a concern – a hunter may have a conflict with a large industrial vessel – what representation does the coastal community have with this issue?

Community suggestions:

- Coastal community members should be on the NPRB Board or the PacMARS Board in order to encourage/facilitate communication with scientific research, facilitate local hires, and implement mitigation measures for ship traffic, changing climate conditions, etc.

- Need to get the United Nations Law of the Sea treaty ratified by the United States.

- Need to prepare for the US chairing the Arctic Council in 2015. Take advantage of existing and upcoming policies and get ready/plan for the future.

- Start at the base by working with coastal communities – build relationships to achieve longevity and stability. Work with people in the field. Introduce yourself to coastal communities. It is better to go to the communities and introduce yourself. All the peoples from youth to elders will have a chance to understand. Share your research information with the coastal communities. We all need to partner together to study the ocean.

- Communities would like to know what researchers are doing. This would promote better communications – and more understanding of the marine environment and ecosystem – of which people are a part. The current lack of communication regarding marine issues is both economically and culturally stressful on communities.

- Inform the community Tribal Government of your pending arrival, meet with the Tribal Government Council, do your fieldwork once it gets approved by the Tribe.

- Recommend that team go to each village. Development of fact sheet and informational flyers are useful.

- Recognize that the tribes are a sovereign government. Ask for permission. Inform the tribal government and the community how your research results will be used, how this information will be applied, and assure (legally) that the data collected are in the best interest of the tribe/community. You will end up with a better product.

- Adhere to the Northwest Arctic Borough Ordinance 12.03 Standards of Research in the Northwest Arctic Borough – re. Informed Consent.

- Ask the community what they want – they will help drive the research. Each community has different needs/different timelines. Do not overlook the needs and interests of the tribes even though sovereignty ends at the coast. Communities rely on the ocean for their food, culture, and livelihood.

- How can the PacMARS project help the community – how to get the parts (research, agencies, co-management, etc.) working/moving in the same directions. When it comes to shared research priorities, a unified voice with, between, and among all stakeholders is best.

- Tribal government councils have monthly meetings and an annual membership meeting – come and present at these forums.

- Work with the elders and the locals – they know things that have been passed down over time. Find out what the people say about an issue or your data.

- Local people should be involved. Come and talk to us about your research and about your results – to the village. Need to train youth!

2e. Nome Community meeting (February 25, 2013)

Attendees:

Lee Cooper [University of Maryland Center for Environmental Science/Chesapeake Biological Laboratory (UMCES/CBL)], Danielle Dickson [North Pacific Research Board (NPRB)], Dolly Kugzruk (Teller Traditional Council), Gay Sheffield [University of Alaska Fairbanks (UAF)], Michael Sloan (Nome Eskimo Community), Edward Soolook (Native Village of Diomede), Stewart Tocktoo (Native Village of Brevig Mission), Stanley Tocktoo (Native Village of Shishmaref), Ellen Tyler [Alaska Ocean Observing System (AOOS)], Sveta Yamin-Pasternak (UAF)

Brief Narrative:

The meeting opened at ~9:00 AM at the UAF Northwest campus. Gay Sheffield provided an introduction to the project, as well as the goal and focus of the meeting. Several presentations by the PacMARS team (Cooper, Sheffield, Yamin-Pasternak), Danielle Dickson from the NPRB, and Ellen Tyler from AOOS followed. The format was informal, with all participants welcome to, and frequently, offering suggestions and observations regarding important marine scientific questions and effective and novel means of communication of science activities and results to local communities. There was a lunch break from 11:45 AM-1:00 PM and lunch was provided at the Northwest Campus followed by resumption of presentations and discussion. The meeting concluded at 4:45 PM.

During the meeting, attendees identified the marine issues of concern via comments and questions, and provided suggestions as follows:

Marine issues of concern:

- Lack of communication from agencies, researchers, and institutions with coastal communities. Port Clarence is under consideration for port development and neither the villages of Brevig Mission or Teller were consulted during that process. How will the development of Port Clarence for ships affect marine subsistence resources? The local economy? Subsistence practices on essential marine resources?

- How do/will the coastal communities be able to participate in the decisions currently taking place regarding ship traffic, shipping routes, future development of marine areas and marine resources?

- What are the effects of cruise ships/industrial ships in general on water quality? Who will be monitoring potential effects? Wastewater discharge from passing large vessels – pollution, sewage, invasive species – these are all threats. Who will be studying/monitoring?

- Old military ordnance are still in the marine environment; How much is around and how to get it cleaned up?

- Marine debris from 2011 Fukushima tsunami event as well as debris from industrial ships – how will these affect the marine vertebrate and invertebrate resources?

- Pollution and contaminants from Russia's coastline communities and ship traffic – what is the current status? How will monitoring be done to mitigate harm to shared marine resources?

- Sunken ships – in Alaskan and Russian waters of Bering Strait – has the fuel been removed? Contaminants? Who monitors these issues and their effects on marine resources? i.e. Sunken ship by Point Jackson ~5 years ago; sunken Russian processor trawler with 200,000 gallons of fuel onboard off Cape Navarin May 2012 (e.g. Kapitan Bolsunovski).

- What are the effects of offshore and nearshore gold dredging on the infauna, epifauna, benthic organisms, diving sea ducks, fish, and benthic feeding marine mammals –from noise pollution, to turbidity, as well as stirring up contaminants on the seafloor from 20th century mining techniques (i.e. arsenic/mercury)?

- Almost no communication from marine researchers to coastal communities regarding upcoming projects, ongoing projects, and/or results of completed projects. Why? How can this be?

- Federal and State projects typically do not include regional traditional knowledge from the coastal communities even though the projects are directly involving essential subsistence resources.

- Trawling impacts on the marine ecosystem and essential marine resources is a large concern for all coastal communities in the Bering Strait region – especially with its reliance on marine resources on the sea floor as well as those marine resources that are reliant on infauna, epifauna, and other benthic organisms as prey.

- We are told that commercial fish stocks are dwindling in the Bering Sea – what are we to expect as impacts on our subsistence harvests from the fisheries moving north?

- What is the participatory process that allows coastal communities and Alaskans to have a voice in the Bering Strait region in maritime issues?

- The Northern Alaskan Pinniped UME seal sickness is still an unknown disease – was it this being caused by radiation or a novel disease? This needs to be studied.

- Ocean acidification – this needs to be monitored/studied.

- There are concerns with coastal erosion as the tundra is falling into the ocean as well as permafrost thaw (affecting the preservation and storage of marine resources for subsistence purposes in coastal communities).

- How will changes in the marine ecosystem, the sea ice, and the weather affect the food chain – the human food chain? How will these affect subsistence uses?

- Use of local community knowledge to only verify shipboard data or mathematical modeling results is not an integrated use of regional expertise of the marine environment/ecosystem.

- The cost of living currently is very high in coastal communities, i.e. gas, store goods. The price increases changes the social structure of the harvest of marine resources. Agencies come and ask us if we would like to leave – NO is the answer. The ocean foods and land foods are nearby. There is no other place for us.

- Limited mobility of communities is a challenge (i.e. church, school, store) vs. migratory nature of the past subsistence livelihoods.

- Will marine mammals be deflected away from our coastal communities due to increased ship traffic?

- How will commercial fishing pressures affect the marine ecosystem and the human use of marine resources throughout Bering Strait region?

- How will shipboard studies be integrated with knowledge obtained locally by other means, e.g. beavers in rivers, sheefish migration, as well as appearance of Atka mackerel, skate, and shark wash ups, etc.

- Future financial constraints are a concern to coastal communities, especially in the face of climate and industrial change in reference to social change.

- Spill response is a concern, including the limited response infrastructure, communications, training, and finances – how will the needs be met by an appropriate level of readiness?

Community suggestions:

- When will the NPRB have a comprehensive report of their multi-faceted integrated Bering Sea project – will that be available to the public/layman?

- Provide results of your research in multi-media formats – posters for public viewing in the communities, use the radio for call-in shows or public service announcements, provide interviews or press releases to the regional newspapers, use the outreach/education outlets (i.e. UAF-MAP, UAF Northwest campus) to assist in regional communications, come to the communities and have face to face meetings, invite community members to the regional hubs for "hub" meetings, etc.

- Communicate frequently, communicate consistently, communicate effectively to be understandable.

- Communities need to understand and/or weigh in on science that is “pure science” vs. science motivated for commercial gain. Can’t stop all projects from happening but communities need to understand the impacts – positive and negative – from science underway in the region.

- Include coastal community members in the conduction of marine research where possible, including youth (youth leaders) and students.

- Include Elders in decision-making for meetings such as this and utilize Elder Advisory Committees. This helps to bring forward voices for the community issues of greatest concern.

- More tribe to tribe unified regional communications.

- Piggyback communication opportunities on other opportunities i.e. Regional conferences, etc.

- We need consistent and effective communication with our Russian neighbors.

3. Key Science Themes and Topics from All Community Meetings

A consensus set of topics that were brought forward in all the community meetings included two overarching themes: a. Security and Stability of Subsistence Resources, and b. Communications and Engagement. Within the subsistence resources theme, marine mammals and seabirds, fishing, and hunting were key sub-topics. In addition, concerns involving oil development and mining, shipping and ship traffic, and environmental changes (ice, physics & contaminants) were identified. The second theme of communication and engagement between local communities and scientists are also clearly important topics for joint efforts moving forward.

3a. Security/Stability of Subsistence Resources

3a.1. Marine Mammals & Birds

All 5 communities expressed concerns related to marine mammals and birds. Bowhead whales, beluga whales, walruses, seals, ducks, geese and polar bears were specifically mentioned. The communities were interested in knowing how changes in sea ice, shipping noise and traffic, contaminants and increased fishing pressure will affect movement and health of these marine mammals. The communities would like monitoring of changes in the migratory patterns and timing of marine mammals, fish and birds. All 5 community meetings brought forward concern about the disease that has recently produced lesions on seals. Communities would like to know what is comprehensively known about the disease.

3a.2. Fishing, Hunting & Food

All 5 community meetings brought forward concerns about trawling and large-scale commercial fishing operations. While the Bering Sea is considered productive, commercial fishing is beginning to move into more northern areas according to our community representatives. There was general concern about not only the species being fished, but also the impact of trawling on benthic communities and the organisms that depend on them for food. Local community authority through sovereign tribal governments ends at the water edge, so subsistence communities are concerned about how conflicts with industrial-scale fishing will be resolved. During all five community meetings, concerns were also expressed about toxins in local foods and how the toxicity and contaminant levels would be studied in subsistence foods now and in the future.

3a.3. Oil & Mining

During all five community meetings, concerns were expressed about oil drilling and both offshore and onshore mining activities. Communities are concerned about the spill response infrastructure, and related communications, training and finances.

3a.4. Shipping & Ship Traffic

During all five community meetings, concerns were expressed about shipping traffic through the Northwest Passage and Northern Sea Route. Concerns included increased noise, pollution, human safety (boaters), wildlife safety and introduction of disease. There was general concern that marine subsistence resources would be impacted by both industrial and cruise ship traffic. The communities wanted to know how the ship traffic would impact migratory patterns, prey availability and if the animals would be deflected away from the coastal communities. They were also concerned about pollution, sewage and invasive species in water discharge from passing vessels.

3a.5. Ice, Physics & Contaminants

During all five community meetings, concerns were expressed about the effects of warmer water temperatures and retreating seasonal sea ice. Community representatives were specifically concerned about how greater open water was increasing erosion and how that was affected the integrity of critical structures (roads, buildings, ice cellars), as well as loss of tundra to the ocean. The communities were also concerned about changes in current patterns and ocean fronts. They asked that these processes be measured in similar ways in order to compare and contrast conditions in time and space. All 5 community meetings brought forward concerns about contaminants in the environment and how changes in physical features (sea ice, erosion, melt run-off, rainfall) would affect transport of contaminants.

3b. Communications and Engagement

In all five community meetings the idea was expressed that regionally specific, community-based input is valuable and under-utilized. They would like studies on the impact of marine ecosystem change on local regional communities, but it should take a more integrated view. These communities consider themselves to be predators integrated into the regional ecosystem, taking and contributing to ecological processes. These communities work to minimize impacts on the environment and adjust social behavior accordingly. The community representatives pointed out the disparities between the existing regulatory framework and their perceived roles in ecosystem processes.

Many meeting participants expressed interest in the idea of synthesis. They wanted to know more about the PacMARS project and suggested that flyers distributed in villages would help explain PacMARS and give updates on the project. The communities asked for tangible products to document a range of information including the state of the ecosystem, outcomes of meetings, outcomes of studies and the importance of subsistence resources. They suggested that clear labels be placed on scientific maps and that scientific information on slides be presented in layperson terms. The meeting participants suggested that information be conveyed in graphical format.

Meeting participants also said that explanations were needed for the relevance of research being conducted. They suggested that regular research updates be provided on marine issues of interest at an announced time and location. The opinion was generally expressed that education and outreach should be explicitly included in research programs. Local communities would like to see their students included in scientific research programs, research cruises and fieldwork.

Community representatives recommended that elders be contacted directly at meetings and individually for input on scientific studies and research needed. They also suggested that when researchers go out in the field, they should exchange information with local residents.

The importance of communication was brought up repeatedly, and some representatives pointed out that there needs to be a long-term communication effort between scientists and local community members. However, this request on a scientist-specific basis is inherently at odds with the current science funding structure, which is dominated by short-term research grants that really do not lend themselves to long-time communication. When multiple projects are supported to the same scientist, the arrangements can permit longer-term communication. Funding agencies need to consider how to maintain a long-term communication channel with local communities in the Arctic while having to rotate funding support among different scientists as well as only supporting 2-3 yr. grant cycles. NPRB, NSF and BOEM, along with other federal and state funding agencies should strategically consider how to maintain continuity of community interactions within the funding limitations of their organizations.

The findings from the PacMARS community meetings were informative and facilitated a better understanding of issues facing local Alaskan communities on the northern Bering, Chukchi and Beaufort sea coasts. We expect to incorporate these insights into the final report of the PacMARS project to be provided to NPRB in summer 2014.

4. Acknowledgements

The PacMARS team members gratefully acknowledge input from all the community representatives who participated in the 2013 community meetings, and those who assisted in facilitating all in the networking and logistics efforts. Individually acknowledgements are made to Lily Anniskett (Native Village of Point Lay), Billy Adams [North Slope Borough (NSB)/Dept. of Wildlife Management (DWM)], Craig George (NSB/DWM), Lee Kayotuk (Native Village of Kaktovik), John Nicholls (Native Village of Nuiqsut), Hugh Olemaun (NSB/DWM), Billy Blair Patkotak Jr. (Native Village of Wainwright), Raphaela Stimmelmayr (NSB/DWM), Edmond Apassingok, Mr. Apatiki, Melvin T. Apassingok, Mark Nupowhotuk, Eddie Ungott, Paul Apangalook, Preston Apangalook, Iver Campbell, and Miriam Oseuk (Gambell), Bryan Rookok Jr., Paul Rookok Sr., James Akeya, Chester Noongwook, Robert Annogiyuk, Arnold Gologregen, Thor Noongwook, Hiram Kiyuthlook, Wilson Okoomealingok, David Akeya, Dylan Iya, Clinton Kogassagan, Mitchell Kiyuthlook, Perry Pungowiyi, Elmer Rookok, and Tom Akeya (Savoonga), Stanley Tocktoo (Native Village of Shishmaref), Edward Soolook (Native Village of Diomede), Stewart Tocktoo (Native Village of Brevig Mission), Dolly Kugzruk (Native Village of Teller), Mike Sloan (Native Village of Nome), Ernest Barger Sr. (Native Village of Buckland), Richard Sage (Native Village of Kivalina), Damian Satterthwaite-Phillips [Northwest Arctic Borough (NAB)], Zach Stevenson (NAB), Ellen Tyler (Alaska Ocean Observing System), Danielle Dickson (North Pacific Research Board), along with PacMARS PIs Carin Ashjian, Lee Cooper, Jackie Grebmeier, Steve Okkonen, and Sveta Yamin-Pasternak who participated in some or all of the community meetings. The Mayor of the NAB, Reggie Joule and staff from the NAB planning department attended the end of the meeting.

Special thanks are extended to Gay Sheffield for leading organizational support for the community meetings. Carin Ashjian also provided critical support for organizing the Barrow meeting. Also, thanks are provided to Nok Aker and Glenn Sheehan of the Barrow Arctic Science Consortium (BASC) and Eric Barnett (Umiaq, LLC) for logistical assistance in Barrow. Meeting notes for this report were collated by Gay Sheffield, Carin Ashjian and Jackie Grebmeier. Eva Bailey at UMCES also provided assistance preparing for the hub meetings and editing an early edition of this report. Logistical and travel support for community participants and PIs to attend the meeting was provided via the North Pacific Marine Research Institute, supported through funding by Shell Production and Exploration and ConocoPhillips. We thank PacMARS co-PI Carin Ashjian for handling the travel arrangements.

APPENDIX A: Participants

Acronym list: AOOS=Alaska Ocean Observing System, CBL/UMCES=Chesapeake Biological Laboratory University of Maryland Center for Environmental Science; Native Village of = Tribal Government; NPRB=North Pacific Research Board, WHOI=Woods Hole Oceanographic Institution; UAF=University of Alaska Fairbanks

January 28, 2013 Savoonga Community Meeting

SAVOONGA	
David Akeya	Savoonga
Tom Akeya	Savoonga
James Akeya	Savoonga
Robert Annogiyuk	Native Village of Savoonga
Lee Cooper	CBL/UMCES
Arnold Gologregen	Savoonga
Jackie Grebmeier	CBL/UMCES
Dylan Iya	Savoonga
Hiram Kiyuthlook	Savoonga
Clinton Kogassagan	Savoonga
Mitchell Kiyuthlook	Native Village of Savoonga
Chester Noongwook	Savoonga
Thor Noongwook	Native Village of Savoonga
Wilson Okoomealingok	Savoonga
Perry Pungowiyi	Native Village of Savoonga
Elmer Rookok	Savoonga
Bryan Rookok Jr.	Savoonga
Paul Rookok Sr.	Native Village of Savoonga
Gay Sheffield	UAF Marine Advisory Program
Sveta Yamin-Pasternak	UAF

January 29, 2013 Gambell Community Meeting

GAMBELL	
Paul Apangalook	Sivuqaq Native Corporation
Preston Apangalook	Native Village of Gambell
Edmond Apassingok	Sivuqaq Native Corporation
Mr. Apatiki	Gambell
Melvin T. Apassingok	Native Village of Gambell
Mark Nupowhotuk	Native Village of Gambell
Eddie Ungott	Native Village of Gambell
Iver Campbell	Native Village of Gambell
Lee Cooper	CBL/UMCES
Jackie Grebmeier	CBL/UMCES
Miriam Oseuk	Native Village of Gambell
Gay Sheffield	Marine Advisory Program
Sveta Yamin-Pasternak	UAF

February 11, 2013 Barrow Community Hub Meeting

BARROW	
Billy Adams	North Slope Borough, Dept. of Wildlife Management
Lily Anniskett	Native Village of Point Lay
Carin Ashjian	WHOI
Danielle Dickson	NPRB
Craig George	North Slope Borough, Dept. of Wildlife Management
Lee Kayotuk	Native Village of Kaktovik
John Nicholls	Native Village of Nuiqsut
Steve Okkonen	UAF
Hugh Olemanu	Native Village of Barrow
Billy Blair Patkotak Jr.	Native Village of Wainwright
Gay Sheffield	UAF Marine Advisory Program
Raphaela Stimmelmayr	North Slope Borough, Dept. of Wildlife Management
Ellen Tyler	AOOS
Sveta Yamin-Pasternak	UAF

February 22, 2013 Kotzebue Community Hub Meeting

KOTZEBUE	
Earnest Barger Sr.	Native Village of Buckland
Lee Cooper	CBL/UMCES
Danielle Dickson	NPRB
Jackie Grebmeier	CBL/UMCES
Richard Sage	Native Village of Kivalina
Damian Satterthwaite-Phillips	Northwest Arctic Borough
Gay Sheffield	UAF Marine Advisory Program
Zach Stevenson	Northwest Arctic Borough
Ellen Parry Tyler	AOOS
Sveta Yamin-Pasternak	UAF

February 25, 2013 Nome Community Hub Meeting

NOME	
Lee Cooper	CBL/UMCES
Dolly Kugzruk	Teller Traditional Council
Danielle Dickson	NPRB
Gay Sheffield	UAF Marine Advisory Program
Michael Sloan	Nome Eskimo Community
Edward Soolook	Native Village of Diomede
Stanley Tocktoo	Native Village of Shishmaref
Stewart Tocktoo	Native Village of Brevig Mission
Ellen Parry Tyler	AOOS
Sveta Yamin-Pasternak	UAF