Framing Arctic Marine Research Initiatives

A FRAMEWORK FOR COORDINATED MARINE ECOSYSTEM RESEARCH IN THE U.S. CHUKCHI & BEAUFORT SEAS
RECOMMENDED CITATION

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Executive Summary

The Interagency Arctic Research Policy Committee (IARPC, a sub-committee of the National Science and Technology Committee) in partnership with the North Pacific Research Board, ConocoPhillips and Shell, recognizes the need to increase our understanding of the marine ecosystem in the northern Bering, Chukchi, and Beaufort seas. Rapidly diminishing ice cover is altering the ecosystem, increasing potential economic activity, and creating geopolitical opportunities and challenges. Federal agencies and industry have diverse mandates to understand implications of, and adapt to, these rapid changes, and research focused on their individual mandates is underway or being planned. Altogether, hundreds of millions of dollars will likely be spent studying diverse aspects of this ecosystem. With sufficient coordination, the constituent efforts can go beyond the individual participant’s mandates and supply a holistic understanding of ecosystem function and response to rapid change.

As a component of the implementation of its five-year research plan, the IARPC and its non-federal partners formed a collaboration team to develop a framework for marine ecosystem studies in the region. The team facilitated development of a conceptual marine ecosystem model for the Beaufort and Chukchi Seas, and coordinated a synthesis study that reviewed current scientific and traditional knowledge and understanding of the Arctic marine ecosystem and detailed access to data sources and archives. The conceptual model and the synthesis study indicated that understanding ecosystem function now and in the future will depend on research in five thematic areas:

- Impacts of winds and ocean currents on nutrient, phytoplankton and zooplankton distribution and production;
- Effects of changes in sea ice and other drivers in the ecosystem on energy pathways (benthic and pelagic systems), ecosystem structure and function, and the phenology and location of key features of the food web (hot-spots in space or time, biodiversity, keystone predators and potential trophic cascades), including access for subsistence activities;
- Nearshore changes driven by ice, winds, currents and freshwater runoff and their implications for vulnerability of biota and human communities, especially due to changes in the habitats of fish, seabirds and marine mammals, and subsequent implications for subsistence use and culture;
- Potential for increased ocean acidification and its anticipated impact on system productivity, structure and function; and
- The role of people within the marine ecosystem as consumers, as a source of perturbation, and as receivers of ecosystem services.

Simultaneously addressing these ecosystem-level research themes and meeting mandates of collaboration team partners will require balancing hypothesis testing with individual timelines and budget constraints. The collaboration team proposes to integrate the individual efforts by:

1. Building upon past efforts and creating formal linkages among past and ongoing projects as appropriate to address framework goals in an integrated manner;
2. Establishing linkages among ongoing projects and their program managers;
3. Identifying important gaps remaining in the framework, determining which can be tackled with project-specific activities and which need new components integrated by design; and
4. Synthesizing information across 1-3 above to create the full framework picture.

Recognizing that program officers among the partners are focused on their organizational mandates, the collaboration team recommends the establishment and support of a Chukchi-Beaufort Marine Steering Group, that will identify new opportunities, synergies, gaps and overlaps between ongoing and planned programs, and make annual recommendations on where to direct new investments to the larger collaboration team, keeping the overall goals and themes of this framework, and the overall understanding of the Chukchi Beaufort marine ecosystem in the forefront.
Introduction

This document brings together the thinking of academic, industry, and government scientists, as well as that of representatives from indigenous communities and conservation organizations to describe an intellectual and organizational framework for coordinating marine ecosystem research in the U.S. Arctic. The Interagency Arctic Research Policy Committee (IARPC) facilitated the effort through workshops and meetings of its Chukchi-Beaufort Sea Ecosystem Collaboration Team (CBCT). ConocoPhillips and Shell made significant financial and intellectual contributions.

PURPOSE

Federal and state governments, industry, indigenous peoples, and conservation organizations are conducting and planning a broad array of disciplinary and inter-disciplinary research in the northern Bering, Chukchi, and Beaufort seas. Each of those efforts has a specific mandate and mission to fulfill in areas ranging from basic and applied research, ensuring ecosystem health, and monitoring, to resource management, international policy, and national security. The varied missions require investigations at different geographic scales and timelines, but are all dependent on knowledge about the Arctic environment, and all are challenged by the rapid pace of change in the region. Tens of millions of dollars are spent annually on marine research in the Arctic, with the Bureau of Ocean Energy Management (BOEM) and the National Science Foundation (NSF) being the largest regular contributors. Many projects are mission-specific, are needed for species-specific management, environmental assessments, and permitting, while others are designed to provide more basic, foundational information. All too often these projects occur in isolation from one another, often collecting similar data and facing similar logistical challenges.

The purpose of this document is to present a framework within which to conduct or sponsor marine environmental research in the U.S. Arctic and foster the scientific collaboration needed to achieve a common understanding of the marine ecosystem and its likely changes in coming decades. Only by having an overarching plan can we leverage our combined resources to take optimal advantage of the varying assets and capabilities of all partners. The aim is to harness the best minds and research capacities so that our scientific understanding can best keep pace with the rapid changes in the Arctic marine ecosystem. IARPC partners can strive to collectively improve and expand the knowledge provided by individual programs through such a framework, with the view that it is but a common vision and not intended to constrain any of the partners. The questions developed herein help define this framework, but it will be incumbent upon the partners to fund the research and test associated hypotheses collaboratively. As such, partners maintain their flexibility in timelines, budgets, and topics, but at the same time retain the ability to contribute to the synergies necessary for a greater understanding and improved management of the Chukchi and Beaufort marine ecosystem.

The intended audience for this document includes executive and senior managers of governmental and non-governmental organizations involved in Arctic marine research or the management or conservation of its natural and cultural resources. This audience includes federal and state agencies, industry, local governments, and conservation organizations. Many of these organizations strategically recognize the principles and potential benefits of ecosystem-based management, and further recognize that no single organization can supply all the data, analyses and syntheses needed for this level of understanding. This framework describes the approaches and mechanisms for coordination and cooperation that can successfully fulfill specific missions and also address key high-level ecosystem themes to inform policy makers, resource managers, industry, and local communities.

BACKGROUND

The Arctic is a region of considerable and growing interest to the U.S. government. In 2013, the White House released the Arctic Research Plan: FY2013 – FY2017 (http://www.whitehouse.gov/sites/default/files/microsites/ostp/2013_arctic_research_plan.pdf) prepared by the Inter-agency Arctic Research Policy Committee (IARPC). Additionally the National Ocean Council and the Interagency Working Group on Coordination of Domestic Energy Development and Permitting in Alaska proposed a comprehensive, multi-agency, science-based
approach for permitting and managing energy and other development issues in the Arctic. The National Strategy for the Arctic Region (http://www.whitehouse.gov/sites/default/files/docs/nat_arctic_strategy.pdf) incorporates the IARPC five-year research plan as part of the strategy to ensure responsible stewardship of the Arctic environment. These strategies advocate ecosystem-based management approaches for U.S. marine ecosystems. To this end, the IARPC Chukchi-Beaufort Ecosystem Collaboration Team produced a straw-man conceptual ecosystem model of the northern Bering, Chukchi, and Beaufort seas and worked with technical experts to develop a conceptual ecosystem model of this Arctic marine ecosystem (Dickson 2014). The team also recognized that attention to priority information needs, and implementation of an ecosystem approach to future marine research in the Arctic, is necessary. This narrowing of scope in priority research areas is a key planning step for providing an intellectual and organizational framework for future Arctic marine research and its coordinated implementation.

In addition to developing a conceptual ecosystem model for the Beaufort and Chukchi seas, the Collaboration Team also supported a synthesis study that was supported by ConocoPhillips and Shell, and managed by NSF and NPRB, with review and input by government managers. The synthesis study, to be completed in early 2015, will provide a review of current scientific and traditional knowledge of the Arctic marine ecosystem, and an accounting of data sources and archives (http://pacmars.cbl.umces.edu/).

Based on the results of conceptual modeling, syntheses, and other scientific results, this framework has been developed with agency and industry support by a subgroup of the interagency Collaboration Team. It provides an opportunity to optimize the leveraging of research by multiple agency and industry partners and presents a unifying theme focused on shared needs of agencies and organizations, and the integration needed to develop enough understanding about the ecosystem structure and function to enable prediction of likely responses to changes in natural and anthropogenic drivers.
FRAMING ARCTIC MARINE RESEARCH INITIATIVES

Understanding a marine ecosystem to a degree that allows for informed management and policy decisions on relevant time and geographic scales, and including the capacity to forecast the impact of changes in ecosystem drivers and anthropogenic activities, is notoriously challenging, especially in the face of rapidly changing forcing mechanisms. It requires collaboration and innovative approaches, and a dedication to disciplined focus, so the effort does not get lost in details or attempt to know it all. Much applied and basic research has been conducted in the Arctic and much understanding about individual ecosystem components exists. This understanding is fundamental to taking the most urgent next steps towards a broader ecosystem understanding. Whereas some ecosystem components remain unstudied or poorly known, what is most lacking for research planning is analogous to a vision of the overall “picture” (i.e., the system) we are trying to assemble from our varied understanding, like pieces of a puzzle (i.e., existing information), a description of effective mechanisms to combine these pieces to form what would be the cover picture of the puzzle box, and a prioritization of research areas, much like identifying the shapes of pieces that are missing so they can fit together.

REVIEW OF EXISTING INPUT

Ample input from community meetings, workshops, assessments, journal articles, technical reports, and synthesis efforts is available to “paint a picture of this puzzle box” that is focused, yet addresses the common scientific needs and core understanding required by natural resource managers, regulators, industry, and other partners interested in Arctic change and conservation. Appendix A briefly summarizes efforts that have helped to define a common core necessary to achieve our intellectual framework goals.

FRAMING THE ARCTIC MARINE ECOSYSTEM RESEARCH AGENDA

The current story of the Arctic is one of environmental change affecting sea ice, marine species, and the people who rely on both. The Arctic marine ecosystem of today is different from that of the past, and it appears that the Arctic of the future will undergo continued changes with increasing effects of human interventions. The studies identified in Appendix A provided valuable insights into separate elements of the Arctic marine ecosystem, and to varying degrees they document baseline information collected from the past and present. A unifying marine ecosystem research framework will allow scientific and management communities to collectively focus their limited resources on identified priority concerns. National and agency strategic plans include goals for stewardship and best available information to inform natural resource managers and policy makers with respect to managed species, protection of traditional lifestyles, energy security, national security, environmental awareness and other goals that would benefit from more holistic approaches to the science needed to adequately evaluate the impacts of human activities on the Beaufort and Chukchi marine ecosystems. There will of course continue to be significant mission-oriented research that will fall outside the science framework (e.g., hydrographic studies, emergency response, etc.) envisioned here, and many other efforts that only partially overlap with the framework (e.g., meteorological studies).

The science framework is important for setting a marine ecosystem-based research agenda that is relevant to many users. It is founded on general understanding of the ecological processes linking the physical environment to valued biological components of the marine ecosystem, from nutrient dynamics to primary and secondary production and energy pathways to the benthos, fish, birds, mammals, and people. Changes in ecosystem processes and states will impact human uses and activities from subsistence hunting to industrial development as well as cultural and social processes. Understanding the drivers of change and their impacts on the Chukchi and Beaufort Seas ecosystem is the fundamental issue to be addressed within this intellectual framework. This understanding will help predict the biological changes that will come with changes in sea ice conditions, temperature, currents, winds, and water stratification. In large part, we are framing the process pieces that we think are missing from the marine ecosystem picture. Without functional or process understanding, we will continue to document variability without achieving the knowledge needed by all Arctic stakeholders to anticipate, mitigate, and adapt to future conditions.
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Robert Harris (PolarTREC 2007). Courtesy of ARCUS
We set forth **two overarching goals:**

- To improve the understanding of changing patterns of advection (of water, energy, nutrients and plankton) and sea ice loss, and their links to winds and storms; associated changes in the phenomenology and energy pathways influencing and maintaining biological production cycles; and consequent changes in the behavior and distribution of marine organisms and their trophic linkages; and
- To increase the quality and accuracy of assessing and forecasting the impacts of ecological change on the human system, and conversely, the impacts of increased human activity on the natural system.

Scientific experts and managers from many disciplines must actively participate in and contribute to ecosystem-level research and relate their efforts to new or existing observing and monitoring systems in order to attribute the direction and magnitude of Arctic change to physical drivers. While this integration is discussed in more detail below, it is not the intent of this document to advocate against discipline-specific projects, but rather to advocate that they work collaboratively with experts in other disciplines so that a proper integration and synthesis can occur.

Within these two broad goals, our intellectual framing process has identified five major interlocking **science themes** (Table 1) that are process-oriented and center on the following:

1. Impacts of winds and ocean currents on nutrient, phytoplankton and zooplankton distribution and production;
2. Effects of changes in sea ice and other drivers in the ecosystem on energy pathways (benthic and pelagic systems), ecosystem structure and function, and the phenomenology and location of key features of the food web (hot spots in space or time, biodiversity, keystone predators and potential trophic cascades), including access for subsistence activities;
3. Nearshore changes driven by ice, winds, currents and freshwater runoff and their implications for vulnerability of biota and human communities, especially due to changes in the habitats of fish, seabirds and marine mammals, and subsequent implications for subsistence use and culture;
4. Potential for increased ocean acidification and its anticipated impact on system productivity, structure and function; and
5. The role of people within the marine ecosystem as consumers, as a source of perturbation, and as receivers of ecosystem services.

Collectively, these goals and themes reflect common information needs, even if a detailed understanding of all these mechanisms is not required nor within the mission of every partner institution. All of the recent strategic documents for Arctic research and management* call for such ecosystem-level understanding. Developing a common intellectual framework of marine research needs supports a host of imminent decisions to be made about Arctic activities. Improved capacity to predict potential changes in the ecosystems of the Bering Strait region and the Beaufort and Chukchi seas should enable Alaska Native communities and resource managers to adapt to ecosystem changes in a proactive rather than a reactive manner. Understanding the linkages among the physical, chemical, and biological components in the Arctic marine system is consistent with the Arctic science goals set forth by the State of Alaska; will help NSF and ONR advance basic scientific understanding of the system; will help BOEM in its mission to distinguish between anthropogenic and environmental impacts; will support USGS, USFWS and NOAA in their risk analyses and reviews under the Endangered Species and the Marine Mammal Protection acts; will help EPA and the Alaska Native Tribal Health Consortium (ANTHC) understand pathways for transfer of contaminants from sediments and seawater to biota; and will help industry plan responsible developments and put their detailed studies and environmental effects monitoring into a broader ecosystem context.

Where federal agencies can contribute to this common need, possible integration mechanisms should be considered in order to achieve the research synergies and cost efficiencies associated with collaborative science approaches. One method that could be used by agencies to determine which common information needs could be addressed collaboratively is Structured Decision Making and supporting tools (from the simplest influence diagrams to the more complex mixed analytical and expert Bayesian Network models). This approach is currently used by USGS and its partners in Alaska, and provides a transparent and quantitative discipline to technical or value-based deliberations.

The five science themes identified above will be investigated over the next several years by academic, tribal, industry, state and federal scientists funded by a variety of different organizations. Closely coordinating those efforts through a common research and organizational framework will enable those individual studies to extend beyond the mandates of individual partners and provide understanding of ecosystem dynamics. For the scientific community, this intellectual framework provides a matrix in which a series of testable hypotheses can be generated to better understand how the Beaufort and Chukchi marine ecosystem functions and is affected by environmental drivers of change.

The Jigsaw Paradigm

COMPLETING THE PUZZLE

Some aspects of the intellectual framework goals and science themes identified in section 2.2 are already being addressed in ongoing research. Appendix B identifies ongoing efforts whose results can be explicitly integrated with one another and incorporated into new and developing models and future research planning. Although we have attempted to highlight the main existing or planned science activities, the list is not exhaustive nor meant to be exclusive. Rather, it should be seen as an invitation to identify further studies that fit, either partially or fully, within this science framework.

Historically, the coordination of technical aspects of scientific research has been done in an ad-hoc fashion at both the management and researcher level (e.g., RFPs, sharing ship time and instruments). On the programmatic side, some formal coordination vehicles have also been developed and implemented by the U.S. Congress since the mid-eighties for some management aspects, such as the National Fish and Wildlife Foundation (1984) and the National Oceanographic Partnership Program (1997).

EXISTING COORDINATION MECHANISMS

Formal mechanisms are needed to address current funding challenges (e.g., ease and speed of funds transfers) when dealing with two or more sponsoring partners. The information needs of every partner should be considered independently and then effectively merged in the partnering process to integrate them efficiently under the umbrella of the EBM approach and to deliver integrated data sets and scientific information. Whichever mechanism is adopted, it must be flexible enough to accommodate the various information needs and procurement processes of all domestic partners, as well as the different legal constraints binding international ones.

To help address aspects of integrated scientific research, several well-established coordination mechanisms exist and have enabled multiple funding sources to come together in one comprehensive solicitation or more than one coordinated solicitation. Some successful partnerships and funding mechanisms include:

- Bering Sea Project (www.nprg.org/bering-sea-project)
- ArcSEES (www.nsf.gov/pubs/2012/nsf12553/nsf12553.htm)
- National Oceanographic Partnership Program (NOPP, www.nopp.org)
- National Fish and Wildlife Foundation (NFWF, www.nwfw.org)
- BOEM/UAF Coastal Marine Institute (www.sfos.uaf.edu/cmi)
- Belmont Forum (www.igfagcr.org)
FRAMING ARCTIC MARINE RESEARCH INITIATIVES

Elizareta Ershova

Marcus Janout
In addition, many federal agencies have developed interagency or cooperative agreements to transfer funds to support ecosystem research. These may not require open solicitations, yet may foster collaboration and integration across different partners.

**INTEGRATIVE MECHANISMS**

For this science framework to achieve its overarching goals, the actual integration of information and programs will be key and will need to include four levels:

1. Building upon past efforts and creating linkages among past and ongoing projects as appropriate to address framework goals in an integrated manner;
2. Building explicit linkages among ongoing projects and their program managers;
3. Identifying the important gaps remaining in the framework, determining which can be tackled with project-specific activities and which need components integrated by design; and
4. Synthesizing knowledge gains across levels 1-3 to create the full framework picture.

Whereas different integrative mechanisms are needed for each level, a positive starting point would be for the partner agencies to articulate science objectives and information needs as interdisciplinary research questions and hypotheses (especially with regard to the five themes presented above) and provide funding, based on research proposals that demonstrate integrative approaches and synergies of research collaboration in the broader ecosystem perspective presented here.

Specifically for the first two integrative levels, results from the ongoing syntheses (SOAR, PacMARS, RUSALCA, CSESP, etc.) should be brought together and linked to past and ongoing projects by holding a workshop, which should have a clearly-defined output document that identifies the linkages and products received or delivered by each project. The identification of clearly articulated topics for synthesis that fit within this framework would help define such products. This effort could be kept up to date through regular PI meetings of relevant past and current project participants where current and new projects plan for the inclusion of past PIs by facilitating necessary travel. Where feasible and appropriate, agreements on ongoing research could be altered or supplemented to include this integrative step. Some additional coordination costs, small in comparison to the costs of the research programs, will be incurred to achieve this goal and should be shared by all participating funding agencies.

The third level will be comprised of new projects that will go forward as single or combined efforts. For single projects, and to ensure level-four integration for all projects, integration can most effectively be achieved by developing common language within RFPs that specifies explicit linkages across projects including data-sharing agreements, field logistics coordination, holding joint PI meetings, creating a program website and SharePoint site, and regular communication among PIs and agency program managers. For components at level three that need to be integrated due to the nature of the question or the resources required to carry out the work, an a priori collaborative mechanism should be established before RFPs are released or funding is granted. On the technical side, linkages among projects could be formalized by identifying high-level synthesis topics as one of the expected outcomes.

Throughout the first three levels, and specifically to reach level-four integration, it is recommended that a Chukchi-Beaufort Marine Steering Group (CBMSG) be established and supported. It is envisioned that this group be composed of representatives from NSF, ONR, NPRB, BOEM, USGS, NOAA and Industry, and act as a working arm and/or steering committee of the Chukchi Beaufort Ecosystem Collaboration Team (CBCT). In this role, the group will maintain an active and regular interaction with the larger CBCT and focus on: identification of new opportunities, synergies, gaps and overlaps between ongoing and planned programs; staying abreast of the latest developments in the field (i.e., publications) on a continuous basis; promotion of interdisciplinary science within and across organizations; organizing and recommending funding regular workshops to gather external input; and recommending, as needed, that synthesis studies be undertaken. Ultimately, this group will issue annual recommendations on where to direct investments to the larger CBCT group, keeping the goals and themes of this framework, and the overall understanding of the Chukchi Beaufort marine ecosystem in the forefront.
FRAMING ARCTIC MARINE RESEARCH INITIATIVES

Francis Weise

Jim Miller (PolarTREC 2011), Courtesy of ARCUS

Francis Weise
International Collaboration/Cooperation

This framework planning is an outcome of the stated need for regional coordination of the nation’s Arctic marine ecosystem research in the U.S. Chukchi and Beaufort seas. It is an important first step, but geographic considerations extending beyond regional and national boundaries are also important. What happens beyond U.S. borders affects the condition of the U.S. Arctic marine ecosystem and the Arctic marine ecosystem as a whole. Thus, our science must consider circum-Arctic connections and their effects on regional weather and climate, sea ice and oceanography, biological productivity, and human uses and development. Examples include teleconnections between water and heat flux in the Atlantic and Pacific sectors and the Beaufort Gyre, climatic impacts of Arctic conditions on lower latitudes, and dispersal pathways across Arctic continental shelves. Administrative and jurisdictional boundaries have little bearing on the ecology of migratory species or the traditional economies of northern Alaska, but the health and condition of such species and economies can be greatly influenced by environmental stressors and habitat conditions beyond Alaska’s boundaries.

Any serious U.S. research effort in the Chukchi-Beaufort seas will benefit significantly from bilateral cooperation with neighboring countries. Russia and Canada, with territorial waters and active research efforts in the Chukchi and Beaufort seas, are obvious partners, though there are other countries (e.g., South Korea) with active research in the area. This planning recognizes the success of ongoing U.S. and international efforts (e.g., RUSALCA, US/Canada Transboundary Fish Survey, DBO), supports their continuation, and sees the value in seeking new areas of potential research cooperation with these and other countries. Perhaps less obvious bilateral and multilateral partners for scientific collaborations with other Arctic nations, or countries with interest in the Arctic, should also be further pursued. This could be achieved through comparative studies, long-term monitoring (e.g., Distributed Biological Observatories), and coordinated research investigations. Norway, with its historical interest in the Barents Sea is a prime example of relevant comparative research, but countries such as Poland and Germany also have active research efforts in the Arctic near Svalbard, and several Asian countries (Japan, China, South Korea) are increasingly conducting marine research on high latitude ecosystems of the Arctic. There are several advantages to such collaborations aside from the obvious synergies from platform sharing and shared scientific expertise. In some cases, the scientific questions about marine ecosystem changes are similar, and even where they are not, there is value in placing the Chukchi-Beaufort area in a circum-polar context. U.S. participation in related research external to the U.S. Chukchi and Beaufort seas will likely benefit those efforts and potentially address key scaling issues. Finally, there are international efforts that are worth mentioning such as the Ecosystem Studies of Subarctic Seas (ESSAS), a regional program under the Integrated Marine Biogeochemistry and Ecosystem Research (IMBER) project; its objective is to compare, quantify, and predict the impact of climate variability and global change on the productivity and sustainability of sub-Arctic marine ecosystems.

The U.S. played a major role in starting that effort when it was part of GLOBEC, and continued collaboration may help establish internationally agreed priorities for comparative studies of various areas. Other efforts include major Arctic research activities funded by the European Union. There has been mutual benefit in the past from formal collaborative agreements with the E.U., and the U.S. would do well to continue the relationship.

Overall, the approach most advantageous to all parties is one of open collaboration that includes exchange of data, technology and manpower, sharing research platforms, and aligning science goals to maximize the benefits gained from scarce research funds.
Sources Used


Kofinas, G., S.B., and J. Magadaniz. 2013. Progress Report, Summary Findings for Project: The Study of Sharing Networks to Assess the Vulnerabilities of Local Communities to Oil and Gas Development Impacts in Arctic Alaska.


Appendix A. Current Efforts

THE PACIFIC MARINE ARCTIC REGIONAL SYNTHESIS (PACMARSTM)

PacMARS, an effort funded by Shell and ConocoPhillips and administered by North Pacific Research Board, National Science Foundation, and North Pacific Marine Research Institute, recommended specific directions for future research:

• Improved understanding of changing patterns of advection and sea ice loss and associated changes in the phenology of biological production cycles and consequence changes in the distribution of marine organisms in space and time;
• A comprehensive carbon budget for the Chukchi and Beaufort seas to identify sources and sinks of organic matter that is advected or produced locally;
• Factors limiting the production of these ecosystems need to be identified, as well as the changes we might expect to see with loss of sea ice and changes in regional climate and ocean dynamics;
• The relationship between productivity and biodiversity needs to be better understood;
• The environmental drivers that cause “hotspots” that aggregate prey for upper trophic level organisms and cause them to persist should be investigated;
• We need to better understand how changes in the environment will modify trophic structure and whether pelagic-benthic coupling will strengthen or weaken;
• Pathways for transfer of contaminants from sediments and seawater to biota should be better described; and
• Food security vulnerability assessments should be undertaken that examine the health and availability of subsistence foods.

The PacMARS synthesis identifies valuable data that already exist that may contribute to addressing these points, yet clearly identifies the need for further research to address the important needs described here.

SYNTHESIS OF ARCTIC RESEARCH (SOAR)

SOAR is supported by the BOEM, and has the overarching goal of using available data, analytical and modelling approaches to identify and test hypotheses that cross scientific disciplines to increase scientific understanding of the relationships among oceanographic conditions, benthic organisms, lower trophic prey species (forage fish and zooplankton), seabirds, and marine mammal distribution and behavior in the Pacific Arctic (http://www.arctic.noaa.gov/soar/index.shtml). The three primary objectives of the SOAR program are to: 1) increase scientific understanding of the biophysical environment; 2) enhance capability to predict future conditions; and 3) effectively transmit findings of the synthesis to local residents, resource managers, science societies, and the general public. In

the framing the research themes for SOAR, the scientific and local communities raised a series of questions which of the purpose of this document have summarized as follows:

• What are the mechanisms that control upper trophic level and benthic hotspots in time and space, how have they changed in the last decade, and how relevant are they to the survival of key ecological, commercial and subsistence species?
• What is the spatial and temporal distribution of whales and seabirds, what controls these patterns, how might the patterns or controlling factors change in the future, and what are the implications for impacts of increased anthropogenic disturbances?

NPRB-IARPC DRAFT SCIENCE PLAN (2012)

A draft science plan led by North Pacific Research Board and IARPC in 2012 identified the need for coordinated, collaborative Arctic marine research and noted the need for better understanding of the processes linking physical changes to biological components of the ecosystem. At the time, the plan was titled “Pacific-Arctic Gateway Ecosystem Study (PAGES)”. NPRB recently committed $6 million to developing an integrated Arctic marine research program and a new science plan is being written that will supersede PAGES. This science plan stated that fundamental to understanding the structure and function of the Bering Strait and Chukchi Sea ecosystem is knowledge of the processes driving cycles of primary production, the relative contributions and fates of various sources of primary production (e.g., phytoplankton, ice algae), and how energy is transferred through the food web and differentially utilized by the benthic and pelagic components of the ecosystem. It argued that both the benthic and pelagic aspects of the ecosystem must be well understood to determine how changes in one may affect the other and how fish, seabirds, marine mammals, and humans are likely to be affected and respond. Some specific areas that were identified as priorities for future study included:

• Loss of sea ice and changes in the timing of sea ice cover;
• Northward movement of species;
• Changes in foraging, pupping, and resting habitat of marine mammals;
• Nearshore changes;
• Effects of Arctic natural resource development and shipping; and
• Effects of ocean acidification and increased noise.

The science plan further suggested that future research efforts consider:

• State (mid-summer, mid-winter) and flux (spring and fall transitions) to determine most relevant or sensitive changes,
• Identifying main driving forces and their relative strength,
• Understanding thresholds and tipping points (transitions between states and functions are not linear), and
• Predicted changes in phenology and match-mismatch scenarios.
ARCTIC CONCEPTUAL MODEL WORKSHOP

IARPC brought 16 ecologists and Arctic experts to Washington, DC on 30 April – 2 May 2013 to begin developing a conceptual model of the Arctic marine ecosystem, as well as testable hypotheses about the future state of the ecosystem. A substantial list of questions and hypotheses were formulated (Dickson 2014). It was noted that on a broad level, and based on the current composition of the atmosphere, substantial global warming is assured at least through 2050. Therefore, independent of any environmental practices or policies, reduction in the volume and extent of Arctic sea ice will continue and may accelerate through mid-century at least. Participants suggested that research may be best focused on areas that ultimately have an effect on ecosystem services or areas in which mitigation measures may be effective or adaptation may occur.

The participants proposed that all research questions be framed with reference to two overarching processes considered to be primary drivers of the system: 1) sea ice thickness, extent and timing; and 2) advection of water northward through Bering Strait. While those processes were believed to dominate ecosystem dynamics in the region, the participants also emphasized the significance of inputs from the broader Arctic basin and beyond. In addition, it was noted that changes in these physical drivers likely will alter the phenotype and, potentially, the spatial distribution and organization of the biological system and interrupt ecosystem services. An ecosystem program should include consideration of humans in three ways: 1) as predators integrated within the food web; 2) as a source of perturbations to the ecosystem; and 3) as receivers of the outputs of the system in terms of ecosystem services. Seasonality, hotspots, hot-times, non-trophic interactions, variability, robustness and resilience need to be addressed.

CHUKCHI SEA ENVIRONMENTAL STUDIES PROGRAM (CSESP) SYNTHESIS

The Chukchi Sea Environmental Studies Program is an industry (ConocoPhillips, Shell, Statoil) funded ecosystem study of the oil lease areas in the northern Chukchi Sea (www.chukchiscience.com). During 2008-2014, the program collected information 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 study varied in scale and scope over the years. In 2013, the team, made up of consultants and academic researchers, produced a special issue in Continental Shelf Research synthesizing the results of the first 3 years of the program (http://www.sciencedirect.com/science/journal/02784343/67).

One of the big conclusions to date is that the study areas in the northeastern Chukchi can best be explained as two contrasting ecosystems lying side-by-side but differing greatly over a scale of only ~25 km. These two ecosystems are contrasted, with one being more pelagic and the other more benthic, hypothesized to occur because of differences in the water masses occurring over the different study areas. The authors note that, in the broadest terms, their results demonstrate the under-appreciated spatial complexity of a region that traditionally has been considered homogenous.

WAKEFIELD SYMPOSIUM REPORT

The Wakefield Symposium (http://seagrant.uaf.edu/conferences/2013/wakefield-arctic-ecosystems/info.php#arcticworkshop) produced a report on a brainstorming process toward a Conceptual Model for Arctic Shelf Ecosystems. The report identified key questions and topics for various aspects of the environment (physical phenomena, major trophic components of food web, etc.) that are important to understanding the ecosystems of interest. Without marching through all the trophic structures discussed, important recurring themes based on those discussion and that are highly relevant to a framework include:

- timing of events, phenology, succession, recruitment, including advective recruitment;
- behavioral responses, documenting important rate processes, identifying and understanding hot spots;
- nutrient transport such as seals moving from benthos to ice surfaces, sea birds as link to terrestrial systems;
- factors influencing light, upwelling, storms, stratification, win;
- advection, inter-sea connectivity, freshwater and river input; and sea ice changes.

USGS REPORT ON OFFSHORE OIL AND GAS IN THE BEAUFORT AND CHUKCHI SEAS (CIRCULAR 1370)

At the request of the Secretary (DOI), USGS conducted an initial, independent evaluation of the science needed to inform decision making associated with the future OCS oil and gas resources in the Beaufort and Chukchi seas. This report provides foundational information on Arctic (1) geology; (2) ecology and subsistence; and (3) climate settings; and more focused examinations of the scientific understanding, science gaps, and science sufficiency questions regarding (4) oil-spill risk, response, and impact; (5) marine mammals and anthropogenic noise; (6) cumulative impacts; and climate change considerations. Lessons learned from the 1989 Exxon Valdez Oil Spill are included to identify valuable “pre-positioned” science and scientific approaches to improved response and reduced uncertainty in damage assessment and restoration efforts. Structured Decision Making approaches are highlighted to illustrate the value of such tools that go beyond, but incorporate, science in looking at what can/should be done about policy and implementation of Arctic development. More than 50 scientific recommendations for Arctic research priorities are described (http://pubs.usgs.gov/circ/1370/). Of special relevance to the framework are:

- Winds are important in shelf and slope dynamics and are poorly understood. Research is needed to understand how the wind wave field and storm surges will change in response to changes in sea ice concentration and extent.
- The large-scale circulation and thermohaline structure of the Beaufort Sea needs to be better understood with consideration given to the large inter-annual variability in winds and ice conditions.
• Impact of the changing ice regime on species and on biological hot spots is poorly understood.
• Continued annual sampling at a series of fixed stations/transsects during a consistent seasonal time-window is required to establish long-term and inter-annual trends.
• We need better information on stock structure and winter distribution and habitats, as well as on seasonal, annual, and geographic variability in diets for most species.
• We are lacking basic biological information for many of the important forage species such as Arctic cod (Boreogadus saida), saffron cod (Eleginus gracilis), sand lance (Ammodites hexapterus), capelin (Mallotus villosus), copepods (Calanus spp.), and euphausiids (Thysanoessa spp.).
• Mechanisms should be developed to better solicit and integrate local traditional knowledge (LTK) as a basic source of information and to fully understand the environmental, ecological, and cultural context of Beaufort Sea and Chukchi Sea subsistence harvests.
• The Chukchi Sea is a dynamic area for marine birds and marine mammals during the summer. Studies to examine their seasonal dynamics related to oceanography, climate, sea-ice dynamics, primary and secondary productivity and movements are necessary.

UNITED STATES ARCTIC RESEARCH COMMISSION (USARC)

USARC publishes its Goals and Objectives every two years (http://www.arctic.gov/publications/goals/usarc_goals_2013-14.pdf). For 2013-2014, it recommends research on five central and crosscutting goals:

• As Arctic climate continues to warm at twice the global rate, climate system “wild cards” requiring greater attention include: (1) rapidly thawing permafrost and the possible release of staggering amounts of carbon into the atmosphere, (2) the sharp decline of Arctic glacial and sea ice (75% reduction from 20 years ago), and (3) the climatic impact of black carbon (soot).
• The hypothesis linking sea ice cover to storm severity is intriguing, and is somewhat controversial, in light of the large amount of natural variability in the climate system and the short observational record of how the atmosphere responds to extreme losses of sea ice.
• Innovative funding approaches and logistical support for long-term monitoring and observing, and incorporation of local/traditional knowledge, at locations and scales that are most useful for scientists, resource managers, and decision makers are needed. The value of these data sets needs to be better communicated to all audiences, including the general public.

BOEM ENVIRONMENTAL STUDIES PLAN AND ADVISORY PANEL INPUT

The Alaska Annual Studies Plan (http://www.boem.gov/akstudies/) supports the goals of the Environmental Studies Program. The ESP is guided by several broad themes, which include: Monitoring Marine Environments, Conducting Oil-Spill Fate and Effects Research, Minimizing Seismic and Acoustic Impacts, Understanding Social and Economic Impacts, Maintaining Efficient and Effective Information Management, Integrating Scientific Results with Local and Traditional Ecological Knowledge. Two questions are fundamental:

• What is the expected change in the human, marine and coastal environment due to offshore activity?
• Can undesirable change be minimized through mitigation measures?

Questions and proposed studies for FY 2014 relevant to this framework include:

• What refinements can we make to our knowledge of major oceanographic and meteorological processes and how they influence the human, marine and coastal environment and improve our model predictions of the fate of potential oil spills?
• What role will currents play in distribution of anthropogenic pollutants near exploration and development prospects?
• What are the current and potential future spatial and temporal use patterns by species sensitive to anthropogenic impacts such as bowhead whales, polar bears, other marine mammals, seabirds and other birds, or fish?
• What changes might occur in socioeconomics and subsistence lifestyles of coastal Alaska communities in light of natural and anthropogenic drivers?
• How can we continue to integrate local and/or traditional knowledge into studies related to the ESP in Alaska?

RUSSIAN AMERICAN LONG TERM CENSUS OF THE ARCTIC (RUSALCA)

The project goal, started in 2003, is to carry out long-term research to better understand causes and consequences of the reduction of ice cover in the northern part of the Bering Sea and the Chukchi Sea (http://www.arctic.noaa.gov/aro/russian-american/). A limited number of CTD stations (Conductivity, Temperature, and Density), along with benthic biological stations, were sampled in 2005 through 2008. A large, multidisciplinary expedition was implemented in 2009 in the Beaufort, East-Siberian and Chukchi seas. Through the RUSALCA Program, an annual cruise is organized to work mainly in research areas of physics of the Bering Strait region. Multidisciplinary and geographically more extensive research cruises have been arranged every 2 to 4 years in the northern part of the Bering Sea, East-Siberian, Chukchi and Beaufort seas subject to the availability of financial resources. Synthesis is ongoing and the program is planned to continue in the future. One emerging hypothesis is that large phytoplankton are growing at such a fast pace that they are able to significantly reduce nutrient concentrations. This would result in zooplankton grazing on the larger phytoplankton while mostly leaving the smaller ones. Overall, these changes would
explain the observed reduction in chlorophyll concentrations and the reduction in primary productivity since the 1980’s. Current findings suggest an increased flow through Bering Strait, so the question arises as to:

• What are the ecological implications in terms of nutrient and zooplankton transport from the Bering into the Chukchi Sea, specifically to species of importance to commercial activities, subsistence harvest or ecological value?

CONSERVATION OF ARCTIC FLORA AND FAUNA (CAFF)

CAFF’s Circumpolar Biodiversity Monitoring Program (CBMP) published an Arctic Biodiversity Monitoring Plan in April 2011 (http://www.caff.is/monitoring-series/view_document/3-arctic-marine-biodiversity-monitoring-plan). The plan identified agreement on:

• A common suite of biological parameters and indicators to monitor and report change across the Arctic marine ecosystems
• Key biotic parameters relevant to marine biodiversity which should be monitored

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION (NOAA) ARCTIC VISION AND STRATEGY

NOAA’s Arctic Vision and Strategy (http://www.arctic.noaa.gov/docs/NOAAArctic_V_S_2011.pdf) lists among its priority goals the following marine research-related topics relevant to this framework:

• Continue to improve sea ice forecasts
• Strengthen our foundational science to understand and detect arctic climate and ecosystem changes
• Improve weather and water forecasts


The IARPC 5-year research plan summarizes collaborations by 15 federal agencies to address important needs in the U.S. Arctic. In terms of marine information needs, it notes the following: Arctic marine ecosystems—driven largely by large-scale changes in sea ice—are moving to new states with the potential for short-term surprises. Priority issues to be studied to better understand these rapid changes include:

• Develop a framework of observations and modeling to support forecasting of sea-ice extent on seasonal to annual scales for operational and research needs;
• Identify and study sites in the Beaufort and Chukchi seas and the contiguous Arctic Ocean where climate feedbacks are active;
• Complete deployment of a Distributed Biological Observatory (DBO) in the Arctic Ocean to create long-term data sets on biological, physical, and chemical variability and ecosystem response; and
• Develop integrated ecosystem-processes research in the Beaufort and Chukchi seas region.

Key research questions put forth in terms of sea ice and Arctic Ocean ecosystems include:

• At what rates will Arctic sea ice diminish over the next 100 years and what will be the consequences for Arctic ecosystems and their inhabitants?
• How will Arctic Ocean acidity change in coming decades and what will be the consequences for Arctic ecosystems and their inhabitants?

NSF PROPOSALS

The topics addressed in NSF proposals are a key indicator of areas of current research interest. For the Arctic, these have broadly included:

• discovery and quantitative documentation of significant primary productivity under the ice;
• the possibility and impact of a switch from sea ice to pelagic biota with the reduction in sea ice;
• the role of benthos in these systems as sea ice cover changes,
• ocean acidification;
• release of methane and of clathrates trapped in permafrost in coastal regions;
• ocean-ice-atmosphere interactions, particularly regarding heat flux, aerosol formation and boundary layer chemistry;
• plankton phenological shifts as seasonality changes;
• land – ocean links, river inputs, coast-shore nutrient movement; and
• water column particle flux and sea ice impact on it.

NORTH PACIFIC RESEARCH BOARD PROPOSALS

Proposals received in response to NPRB’s annual call for proposals provide an indication of what the scientific community views as priorities for Arctic marine research. Some examples of topics that these proposals focused on include:

• changes in sea ice extent and timing and effects on primary and secondary production, trophic linkages, and habitat;
• changing circulation patterns;
• assessment of benthic meiofauna, complexity of benthic habitat, and sensitivity of benthic communities;
• Arctic cod population structure, habitat, and trophic relationships;
• distribution of secondary production and marine mammals;
• climate change effects on vital rates of biota;
• marine mammal sensitivity to oil, oil dispersants, and anthropogenic disturbance;
• food security; and
• ocean acidification.

In addition to these formal inputs, many conversations with local community members, managers and policy makers have taken place, providing further useful ideas and information needs. Taken together, these reports, documents and conversations provide community input to help NPRB develop guiding principles for funding future work.
Appendix B. Existing or Planned Pieces of the Puzzle

Several projects exist that represent pieces of the jigsaw puzzle that, when put together, could lead to broader understanding of the Chukchi-Beaufort Sea ecosystem. Here, we identify some of those pieces in hope that they will be integrated with each other and with research funded in the future. Although we have attempted to highlight some main existing or planned inputs, this list should not be considered exclusive, but rather an invitation to identify further studies that fall within this frame.

**Marine ARctic Ecosystem Study (MARES)** – MARES is a NOPP initiative planned to begin in 2015 as a multilateral, integrated science approach to study the Beaufort Sea Ecosystem—its structure and dynamics as well as its corresponding physical environment. MARES attempts to integrate management aspects from 9 partners and across disciplines (marine ecology, physical oceanography, marine chemistry, and social science) and requires the interpretation of its results and findings through an intensive data synthesis and conceptualization. MARES will also attempt to integrate observational and modeling perspectives in order to gain insight on complex processes such as inter-system feedbacks. Through several coordination mechanisms, the MARES will also integrate simultaneous research activities taking place in and around the Beaufort Sea. The MARES will rely on state-of-the-art technologies to provide insight about the current state of the Beaufort Sea ecosystem as well as the sense and direction of contemporaneous trends.

POC: Guillermo Auad (Guillermo.Auad@boem.gov)

*Chukchi Acoustic, Oceanographic, and Zooplankton (CHAOZ)* – 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 (BOEMRE, now BOEM) to document the distribution and relative abundance of whales in the eastern Chukchi Sea ecosystem (an area of oil and gas exploration) and to study the relationship between whale distribution and oceanographic conditions, indices of potential prey density, and levels of anthropogenic activities. The study includes four component projects: oceanography, passive acoustics, zooplankton, and climate modeling. Passive acoustic moorings, deployed concurrently with bio-physical moorings will provide previously unattainable year-round assessment of the seasonal occurrence of bowhead, humpback, right, fin, gray, and other whales in this planning area and their response to environmental changes (including oceanographic conditions, climate, indices of potential prey density, and anthropogenic activities).

POC: Heather Crowley (heather.crowley@boem.gov)

**Aerial Surveys of Arctic Marine Mammals (ASAMM)** – The 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 project is conducted through an inter-agency agreement between the Bureau of Ocean Energy Management and NOAA’s Alaska Fisheries Science Center. The goal of the project 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. Data from the ASAMM surveys will be used to relate variation in marine mammal distribution or abundance to other variables, such as physical oceanographic conditions, indices of potential prey density, anthropogenic activities, and other research goals which intersect with those of CHAOZ.

POC: Janet Clarke (janet.clarke@noaa.gov)

**Distributed Biological Observatory (DBO)** – The DBO is envisioned as a change detection array along a latitudinal gradient extending from the northern Bering Sea to the Barrow Arc. 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, and continued to sample these stations through 2013. Since 2012, a U.S. DBO Implementation Team (IT) has met with the overarching goal of implementing sampling in all five DBO regions by 2015. The DBO IT is now focused on bringing together data from 2010-2013 sampling efforts to demonstrate the value-added of this national and international sampling shared-data approach to the investigation of biological responses to a rapidly changing Arctic marine ecosystem. Expanding from the Pacific Arctic sector, the DBO will also serve as a framework for international research coordination via the Arctic Council Circumpolar Biodiversity Monitoring Program (CBMP), and is recognized as a task of the pan-arctic Sustaining Arctic Observing Network (SAON) program.

POC: Sue Moore (sue.moore@noaa.gov)
Russian American Long Term Census of the Arctic (RUSALCA) – The RUSALCA program addresses long term change across several disciplines (i.e., biological, physical, including the study of sound propagation in the ocean and sea ice reduction impacts on the ecosystem, climate scenarios and marine chemistry). The RUSALCA program is synthesizing multi-disciplinary information observed since 2004 and is expected to be completed in early 2015. Most of the findings and issues identified are being folded into products emerging from PacMARS and SOAR, although some specific products that will fit well within this frame are:

- Time-series of water flow and water mass properties through Bering Strait;
- Time-series of phytoplankton and zooplankton abundance and distribution; and
- Time-series of benthic-biota distribution and abundance.

During the second decade of the RUSALCA program, the U.S. and Russian Federation will focus on gathering long-term multidisciplinary observations towards understanding the causes and consequences of the reduction in sea ice cover in the Pacific Arctic Ocean. Understanding how heat fluxes from the Pacific and Atlantic waters trigger the loss of sea ice in this region is critical to determining linkages between the Arctic Ocean climate and impacts on the mid-latitudes. It is expected that this upcoming 5-year RUSALCA program will be a fundamental building block of a larger synoptic survey of this region in the Pacific Arctic, possibly supported by multiple platforms provided by the countries within the Pacific Arctic Group (e.g. Korea, Japan, Canada, China, Russia and the U.S.) in addition to other interested stakeholders. The program will be called upon to provide benchmark data to the prediction, forecasting and modeling communities from the coast of Alaska to the Pan Arctic-Arctic Council working groups. Specifically for the next few years, the RUSALCA program is interested in:

- Bering Strait flow and pathways on the Chukchi Sea and connectivity with East Siberian Sea and continuity of shelfbreak jet;
- Unveiling the pathways of polymeric-formed waters;
- Shelf-basin connectivity (transport and properties);
- Interaction between nutrient flux, primary production and zooplankton dynamics; and
- Bottom sediment cores from the deep Chukchi Sea borderland, East Siberian shelf areas, as well as Makarov and Canadian basins for environmental reconstruction for the last 100,000 yrs.

POC: Kathy Crane (kathy.crane@noaa.gov)

Bering-Aleutian Salmon International Survey (BASIS) – BASIS began in 2002 as a coordinated program of cooperative research on Pacific salmon in the Bering Sea. The goal of BASIS research was to clarify the mechanisms of biological response by salmon to the conditions caused by climate change in the Bering Sea. Since then however, surveys have collected data on many forage fish species and ocean conditions and its geographic coverage has extended into the Chukchi Sea providing a seamless grid of data that connects the Bering Sea and the High Arctic. The program has since been renamed Bering Arctic Subarctic Integrated Survey (http://www.afsc.noaa.gov/ABL/EMA/EMA_BASIS.php).

POC: Ed Farley (ed.farley@noaa.gov)

Marginal Ice Zone (MIZ) – This 5-year (2012-2016), multi-investigator, multi-national, project is a Departmental Research Initiative of Code 32, Office of Naval Research. The main field experiment began in March 2014 in the eastern Beaufort Sea and will conclude in September 2014 in the western Beaufort Sea/eastern Chukchi Sea. The scientific objectives of the project are:

1. Understand the physics that control sea ice break up and melt in and around the ice edge, i.e., the marginal ice zone (MIZ).
2. Characterize changes in physics associated with decreasing ice/increasing open water.
3. Explore feedbacks in the ice-ocean-waves-atmosphere system that might increase/decrease the speed of sea ice decline.
4. Collect a benchmark dataset for refining and testing MIZ models.

The technical objectives of the project are:

1. Develop and demonstrate new robotic networks for collecting observations in, under and around sea ice.
2. Improve interpretation of satellite imagery.
3. Improve numerical models to enhance seasonal forecast capability.

The MIZ project is concerned primarily with the physical environment and processes, but in a collaboration with the Korea Polar Research Institute (KOPRI), it also includes an investigation of ocean biogeochemistry. Further information about the project is available at http://www.apl.washington.edu/project/project.php?id=miz.

POC: Martin Jeffries (martin.jeffries@navy.mil)

Sea State and Boundary Layer Physics – This 5-year (2013-2017) multi-investigator, multi-national, project is a Departmental Research Initiative of Code 32, Office of Naval Research. The project will use a combination of in situ observations (main field experiment planned for late September 2015 through early November 2015 in the Chukchi-Beaufort seas), remote sensing and numerical modeling to address the following science objectives:

1. Develop a sea state climatology for the Arctic Ocean, and more particularly for the Beaufort and Chukchi seas.
2. Improve wave forecasting in ice-covered waters.
3. Improve theory of wave attenuation and scattering in the sea ice cover.
4. Apply wave-ice interactions directly in integrated Arctic system models.
5. Understand heat and mass fluxes in a wave-affected air-ice-ocean system.

Further information about the project is available at http://www.apl.washington.edu/project/project.php?id=arctic_sea_state.

POC: Martin Jeffries (martin.jeffries@navy.mil)
Framing Arctic Marine Research Initiatives

**Seasonal Ice Zone Reconnaissance Surveys (SIZRS)** – This ONR-funded, multi-investigator project coordinated by the Polar Science Center, Applied Physics Laboratory, and University of Washington takes advantage of the U.S. Coast Guard Arctic Domain Awareness flights out of Kodiak, Alaska to make atmosphere–ice-ocean observations in the Beaufort Sea. Once or twice a month during May to September, the following observations are made along longitude 150°W: (1) ocean temperature, salinity and currents; (2) sea ice freeboard and surface roughness; (3) visible and infra-red photography of the ice and ocean surface; (4) atmospheric profiles of temperature, humidity and winds; and (5) cloud top and base.

POC: Martin Jeffries (martin.jeffries@navy.mil)

**Alaska Ocean Observing System (AOOS) Moorings** – AOOS (pending annual funding allocations) hopes to deploy a mooring in the Chukchi Sea southeast of Hanna Shoal during Aug. – Sep. in 2014 – 2018. The mooring will measure current strength at 3 – 30 m depth, significant wave height, period and direction, temperature, pressure, salinity, acoustic backscatter (38, 125, 200 & 460 kHz), ice draft, and nitrate. In some years, it will also measure dissolved oxygen, colored dissolved organic matter, optical backscatter, photosynthetically active radiation, fluorescence, partial pressure of CO₂, and particle size spectra & concentrations. AOOS also has a tentative plan to deploy a second similar mooring in the Beaufort Sea in 2016-17, and to deploy a wave buoy in Bering Strait that would include wave, wind, air and water temperature sensors.

POC: Molly McCammon (mccammon@aooos.org)

**State of Alaska Ocean Acidification Program** – The State of Alaska (UAF) and federal partners have deployed ocean acidification (OA) monitoring instruments in the Gulf of Alaska (Sitka and Seward), southeastern Bering Sea and Beaufort Sea; pH is measured at DOB sites as well (e.g., Chukchi Sea). UAF is conducting a vulnerability assessment based on predictions of OA change in different regional settings and the economic and cultural values of fisheries in Alaskan communities.

POC: Jeremy Mathis (jeremy.mathis@noaa.gov)

**USGS Changing Arctic Ecosystem Initiative** – The USGS science initiative, “Changing Arctic Ecosystems”, is designed to identify and understand the linkages between physical processes, ecosystems, and wildlife populations. Knowledge-based modeling structures, such as Bayesian Networks, are being used to identify science priorities and integrate the work at regional and larger scales. In addition to understanding environmental influences on DOI managed species (e.g., fish, birds and mammals), other objectives are addressing foundational needs for biomarker development (genomic and physiological parameters as sensitive indicators of change); hydrological and landscape modeling; data management and integration; and long-term monitoring protocols. CAE studies examine how and why changes in the ice-dominated ecosystems are affecting wildlife to provide a better foundation for understanding the degree and manner in which wildlife species and humans respond and adapt to rapid change in the physical environment (e.g., enhancing forecasts of polar bear and walrus population responses to sea ice loss).

CAE goals include:
- Provide information on wildlife species and their current and future responses to ecosystem changes including warming temperatures, diminishing sea ice, increasing coastal erosion, deteriorating permafrost, and changing water regimes.
- Provide information for management decisions related to development of oil, gas and mineral resources on BLM lands and on the Outer Continental Shelf managed by BOEM.
- Provide data and research to inform policy, such as the Endangered Species Act, Marine Mammal Protection Act, subsistence and co-management actions.

POC: Dr. Mark Shasby (shasby@usgs.gov)

**BOEM Environmental Studies Program** – Over four decades, more than $450 million has been dedicated to research in Alaska. Some of the major recent arctic projects that support broad ecosystem-based and process-oriented collaborative research interests are described in brief below.

POC: Dee Williams (dee.williams@boem.gov)

**Surface Current Circulation and Mesoscale Meteorology**: Over the last decade, a thematic body of research has produced voluminous information on the temporal and spatial structure of ocean surface currents in the Chukchi and Beaufort seas. Through collaboration with UAF, instruments such as moorings, gliders, drifters, and high frequency radar deliver ocean current data and mean circulation under different wind and sea ice coverage conditions. This research enhances the quality of broad environmental assessments by improving knowledge about the physical transport of water mass, zooplankton, contaminants, and other quantities in hotspot locations such as Barrow Canyon (Weingartner et al. 2012; Weingartner et al. 2009). Also, since 2006, the ESP collaborated with UAF to achieve accurate simulation of the Beaufort and Chukchi seas’ surface wind and associated meteorology. The research compiled meteorological data from over 250 station locations extending from Russia through Alaska to Northwest Canada, over a 30-year time span to support hind-cast modeling simulations that improve understanding of regional climate conditions (Zhang et al. 2013). Other components of this research include compilation of high resolution satellite imagery to reveal changing landfast ice coverage and trending sea ice effects associated with climate change (Mahoney et al. 2012; Hearon et al. 2009).

**Oceanographic General Circulation Modeling and Oil-Spill Risk Analysis**: The ESP has continually sponsored updated general circulation model simulations covering the Beaufort and Chukchi seas, as well as the Bering Sea and Gulf of Alaska. In partnership with experts from both private and university sectors, these modeling studies provide ten to twenty years of relevant modeled fields, such as gridded wind, surface water, ice cover, and ice velocity to support in-house oil spill trajectory modeling (Curchitser et al. 2010; Curchitser et al. In press; Weingartner and Kasper 2011).
information about these fields is important for evaluating the fate of spilled oil in the region and evaluating the potential impacts on biota associated with these systems. In addition, the ESP develops estimates of oil spill occurrence rates for federal waters based on historical platform, pipeline or worldwide tanker crude oil spill rates. Since 2002, the ESP has incorporated a “fault-tree” approach to adapt spill occurrence rates from elsewhere to arctic conditions (Bercha 2011). Oil spill risk analysis has driven other ongoing research of broad interest to the science community, including shoreline coastal habitat mapping (Harper and Morris 2014), onshore spill statistics (Robertson et al. 2013), oil weathering and transport properties, and spill dispersion tracking.

**Ecosystem Monitoring in the Central Beaufort Sea:** The ESP has sponsored long-term monitoring projects in the central Beaufort Sea near the offshore production platform of Northstar since 1985. After construction of Northstar, a series of interdisciplinary research occurred in phases under the common title “Arctic Nearshore Impact Monitoring in the Development Area (ANIMIDA),” including phase one (1999 - 2002), phase two (cANIMIDA, 2004 - 2007), and phase three (ANIMIDA II, 2013-2018). The consistent monitoring efforts have included: hydrocarbon and metal characterization of sediments; concentrations and dispersion pathways for suspended sediments; integrated monitoring and accumulation of contaminants in biota; monitoring the Boulder Patch; and annual assessment of subsistence bowhead whaling near Cross Island (Neff et al. 2009; Neff 2010; Dunton et al. 2009; Galginaitis 2014).

Sampling stations have overlapped through the years, and have recently extended monitoring efforts into Camden Bay with a suite of instrumentation designed to be consistent with the Distributed Biological Observatories, namely collections of: zooplankton samples using bongo net trawls; benthic dwelling invertebrates using van Veen grabs and otter trawls; and pelagic fishes using beam trawls. Physical oceanographic data are also collected using various instruments to measure salinity, temperature, and density and to analyze water column nutrients, trace elements, and acidification data at specific depths. At select stations, additional instrumentation is used to collect current profiling data and bio-acoustic data from marine mammals.

**Beaufort Sea Marine Fish and Lower Trophic Surveys:** In partnership with NOAA, UAF, and the Canadian Department of Fisheries and Oceans, the ESP has sponsored over the last decade a series of systematic surveys of marine fish and invertebrate lower trophic species across the shelf break and slope (20-1000m) in the western, central, and eastern Beaufort Sea, (Loggerwell et al. 2010; Konar and Ravelo 2012; Gray 2014). The studies deliver interim baseline and monitoring knowledge of fish species, trophic links, fish distribution and relative abundance, while they utilize sampling methodologies adapted for Arctic conditions to delineate specific ecological food-web relationships (Bluhm et al. 2014; Thorsteinson et al. 2014). Concurrent and planned research components also seek to connect this marine habitat to near-shore and coastal waters. Related projects have also documented expansion of salmon observed by North Slope residents (Carothers 2013) and investigated life stage vulnerabilities of Arctic cisco (Murphy et al. 2007; Zimmerman and von Biela 2014) and Arctic cod (Talbott 2014). For more than three decades, the ESP has also funded monitoring research in the “Boulder Patch”, an isolated kelp community in Stefansson Sound, to understand the biology and ecology of the fauna and the associated diverse and abundant populations of benthic organisms (Dunton et al. 2009; Konar 2012).

**Ecosystem Monitoring in the Northeast Chukchi Sea:** In 2008, the ESP initiated the project “Chukchi Offshore Monitoring in the Drilling Area: Chemistry and Benthos”, involving open-water baseline measurements of benthic chemical and biological resources in federal waters of the Chukchi Sea, including sediment geochemistry, characterization of benthic and epibenthic communities, and food web structure. A research team led by UT-Austin focused on trophic structure and the potential for bio-accumulation of anthropogenic chemicals into food webs (Dunton 2012; Dunton et al. 2014a, 2014b). The subsequent and ongoing “Hanna Shoal Ecosystem Study” extends this ecological monitoring and expands the geographic area of study. The current project also documents the circulation and density fields, as well as ice conditions, at Hanna Shoal, and examines important chemical, physical and biological interactions with the unique ecology in this highly productive area. The project aims to produce a better understanding of the seasonal, inter-annual, and long-term climate change impacts on the regional ecosystem.

**Eastern Chukchi Sea Marine Fish and Lower Trophic Surveys:** Since the 1980s, the ESP produced decadal marine fish surveys in the Chukchi Sea (Frost and Lowry 1983; Barber 1993). In 2012, the USDOI ESP partnered with NOAA and UAF to initiate a new two-year comprehensive field study of the water masses, circulation and biological resources of the northeastern Bering Sea and Chukchi Sea marine ecosystems from August through September under the name ‘Arctic Integrated Ecosystem Survey.’ The baseline data collection and analysis helps define the regional structure, function, and ecology of the plankton, fish and shellfish communities under current climate and habitat conditions. Preliminary results show that the biomass of demersal fishes in 2012 was similar to or lower than similar survey results from 1990, while the relative species composition remained remarkably stable over a 30-year period (Norcross et al. 2012). Nearshore fisheries work has included collaboration with NPRB and NOAA on the “Alaska Coastal Ecosystem Survey”, which intends to characterize spatial and temporal patterns in distribution, condition, energetics and prey preferences of nearshore fish. This three year program adopts a multi-faceted field and laboratory-based approach using shallow-draft autonomous sampling vessels, while integrating acoustics, current measurements, and beach seining with energetic and life ecology techniques. Sample sites will focus in the vicinity of Barrow and Wainwright. The ESP is also amassing samples for quantifying Arctic food web connections through inter-related diet, isotope and fatty acid analyses (e.g. Dunton 2012).

**Arctic Marine Mammal Research and Monitoring:** Since 1974, the ESP has maintained an extensive monitoring program that involves large scale aerial surveys to document annual distribution and rel-
ative abundance of marine mammals in the Beaufort and Chukchi seas. Working in close partnership with the NOAA-NMFS National Marine Mammal Laboratory over the last decade, the annual aerial surveys have recently combined with other multi-disciplinary projects that focus primarily on bowhead whale movement and feeding variability so that biological data can be combined with oceanographic and atmospheric data to better understand the relationship of marine mammal species with their habitats (Clarke et al. 2013, 2014; Shelden and Mocklin 2013). Concurrently, passive acoustic recorders have been deployed to document ambient noise and to record seasonal occurrence of vocalizing marine mammals in association with known environmental conditions. In partnership with the Alaska Department of Fish and Game, more than 50 whales have been tagged with satellite transmitters to produce new information about the seasonal migration and behavior of endangered whales (Quakenbush et al. 2013). These projects explicitly work to integrate inter-disciplinary data with local traditional knowledge and active participation by Alaska Native hunters. Similar tagging programs have also focused on ice seals, walrus, and polar bear. Such data have been invaluable in the ongoing effort to document and model the consequences of climate change on the Arctic ecosystem.

**Marine Waterfowl and Shorebird Monitoring:** In recurring partnership with USGS, USFWS, and UAF, the ESP has sponsored aerial, boat and ground surveys to discern spatial and temporal baseline patterns of marine waterfowl, shorebirds, and ESA avian species distribution. Sponsored studies evaluate avian species composition, relative abundance, migratory pathways, foraging behavior, community characteristics and species-specific habitat selection in the Chukchi and Beaufort and northern Bering seas. Birds of recent special concern have included: eiders (Sexton 2014; Quakenbush et al. 2009), loons (Schmutz 2012), and phalaropes (Powell et al. 2010). Recent improvements in satellite telemetry have yielded new information on the distribution and movements of long-tailed ducks and eiders, many of which stage, migrate, or molt in the eastern Chukchi Sea then transit to other regions.

**Subsistence, Traditional Knowledge, and Social Monitoring:** Over the last decade, the ESP partnered with private contractors to focus social science research on spatial and temporal data collection that documents and monitors changing subsistence harvest patterns. Researchers have outfitted marine hunters with Global Positioning Systems to record boat tracks and waypoints, including hunter observations, strikes, and harvest sites, and have involved mapping discussions with harvesters in Beaufort and Chukchi Sea coastal communities (Galginaitis 2014; Braund 2010; Braund 2013a). Harvest of terrestrial resources has also been documented, most notably including data about local knowledge and experience in harvesting anadromous fish (Murphy 2007). In partnership with UAF, another major research focus has utilized social network analysis to map subsistence sharing networks in Kaktovik and Wainwright as a means to assess the food security and community resilience in response to environmental and social stresses (Kofinas et al. 2013). In collaboration with working groups of the Arctic Council, a formal survey of community social indicators is also underway that will help to standardize international measures for assessing community well-being as well as support ongoing monitoring and mitigation research focused on cumulative impacts (Braud 2013b). Studies have also documented local and traditional knowledge, particularly of bowhead whales by Wainwright residents (Quakenbush and Huntington 2010) and the use of salmon by Barrow and Nuiqsut residents (Carothers 2013). Alaska Native people have played an important role in various satellite tagging efforts involving whales, walruses, ice seals, and char. All of the studies have been undertaken with full support and participation by local communities and tribal councils, while new collaborative efforts are underway to organize and implement local panels of traditional knowledge experts to facilitate enhanced integration with external science teams (Williams 2012).

**Studies Proposed for FY 2015** that would fall within the framework include: Assessment of Multiple Ocean Circulation Models to Support Ensemble OSRA Experiments, Arctic Benthic Ecosystem Assessment, Synthesis of Oceanographic and Climate Data for Environmental Analysis and Model Validation, and Development and Assessment of Unmanned Aerial Systems for Estimation of Regional Abundance and Demographic Rates of Pacific Walruses

**Chukchi Sea Environmental Studies Program synthesis** – A full synthesis of the last 6 years of data collection is ongoing. The program collected data in and around lease areas on physical oceanography (CTD casts and gliders), ocean acidification, benthic community composition and density, fluorometry, seabird and marine mammal abundance and distribution, acoustics, and metocean. The program also occupied at least one of the DBO lines annually.

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**North Slope Borough/Shell Baseline Studies Program** – The North Slope Borough and Shell have entered into an agreement to fund the Baseline Studies Program that addresses research questions of concern to residents of communities in northern Alaska. Representatives of each North Slope Borough community serve on the steering committee alongside representatives of the North Slope Borough Department of Wildlife Management and Shell, as well as four independent scientists. Research priorities are set annually and a portion of funds is reserved to respond to issues that arise unexpectedly, (e.g., unusual mortality events). Some current research priorities include: investigations of forage fish (including community-based monitoring); studies of prey for bowhead whales ( euphausiids and copepods) and other marine mammals (and the processes that aggregate prey); high-frequency (HF) radar measurements of surface currents; drifter measurements of sub-surface currents; sea ice drifter observations; and mapping subsistence use areas.

The Northwest Arctic Borough also recently entered into a similar agreement with Shell and is still in the process of establishing a structure.

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Synthesis of Arctic Research (SOAR) – It is anticipated that SOAR will be publishing a special issue in Progress of Oceanography with the following contributions:

**Theme 1** – The ‘New State’ of the Pacific Arctic sector: Observations and models of sea ice loss, effects on primary production and acoustic ecology:
- Variability in annual persistence, breakup, and formation of sea ice cover in the Pacific Arctic region
- Primary production in the Pacific sector of the Arctic Ocean
- An ocean acidification vulnerability index for the Pacific Arctic region
- A decade of environmental change in the Pacific Arctic region
- Mechanisms for enhanced trophic productivity in Barrow Canyon, Chukchi Sea

**Theme 2** – Response of mid-level trophic species to the ‘New State’ of the Pacific Arctic: Benthic and pelagic invertebrates and forage fishes:
- Benthic system analysis at predator—prey “hotspot” sites along a latitudinal gradient in the northern Bering and Chukchi seas
- Fish of the Beaufort and Chukchi seas
- Consequences of summer sea ice loss to seabirds and seals in the Chukchi and Beaufort seas

**Theme 3** – Response of upper-trophic species to the ‘New State’ of the Pacific Arctic: Marine mammal and seabird distribution, relative abundance and phenology:
- A year in the acoustic world of western Arctic bowhead whales
- Western Arctic bowhead whale body condition and links to summer sea ice and upwelling in the Beaufort Sea
- Seasonal and spatial patterns in marine bird and mammal abundance and distribution in the Pacific Arctic: A comparison of biologically important pelagic areas
- Oceanographic and other factors associated with western Arctic bowhead whale “hotpots”
- Relationship between beluga whales, Arctic cod, and oceanographic conditions in the Barrow canyon and at the shelf break of the western Beaufort Sea
- Scale matters: Upper trophic level species and what they can tell us about ecosystem shifts in the Beaufort Sea

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**Arctic System Studies** – Current NSF awards that fall within this framework include:
- Ocean Acidification in the Canada Basin: Roles of Sea Ice
- Forum for Arctic Modeling and Observational Synthesis (FAMOS)
- Continuation of Development and Application of Arctic Ocean Finite-Volume Community Ocean Model (AO-FVCOM) to Improve Understanding of Arctic Changes
- Terrestrial Linkages to Microbial and Metazoan Communities in Coastal Ecosystems of the Beaufort Sea
- Late Quaternary Sea Ice History of the Beringian Arctic Gateway
- Collaborative research on the state of the Arctic sea ice cover: An integrated seasonal ice zone observing network (SIZONET)

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**North Pacific Research Board (NPRB)** – In spring 2014, NPRB committed $6 million towards the development of an integrated Arctic research program. The program is currently under development and will likely occur in 2016-2020. NPRB's goal is to develop a cohesive and synthetic research program that advances understanding of the Arctic marine ecosystem. NPRB will target research that supports effective management, sustainable resource use, and ecosystem information needs. The geographic extent of the program may include the northern Bering Sea (i.e. north of St. Matthew Island), the Bering Strait, the Chukchi Sea and/or the Beaufort Sea. Potential areas of research might include:
- Ecosystem structure and processes, including energy pathways and production cycles, and their relationship to sea ice dynamics and advection patterns
- Species dynamics and interactions, including trophic linkages
- Projected shifts in distribution and phenology in the context of climate change
- The impact of ecological change on communities and ecosystem services

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THIS DOCUMENT IS A PRODUCT OF THE CHUKCHI AND BEAUFORT SEA ECOSYSTEM COLLABORATION TEAM. MORE INFORMATION MAY BE FOUND AT WWW.IARPCCOLLABORATIONS.ORG.