Arctic Program Implementation Plan

2015-2021

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I. Introduction

The North Pacific Research Board (NPRB) has conducted interdisciplinary marine ecosystem research programs in the Bering Sea (http://www.nprb.org/bering-sea-project) and Gulf of Alaska (http://www.nprb.org/gulf-of-alaska-project), and this document outlines plans for implementing a similar program in the Arctic (http://www.nprb.org/arctic-program). The Arctic program will be conducted in partnership with the Bureau of Ocean Energy Management (BOEM) and North Slope Borough/Shell Baseline Studies Program. Other funding entities are likely to join the partnership as the program develops. Some projects funded separately by organizations such as National Science Foundation (NSF), National Oceanic and Atmospheric Administration (NOAA), U.S. Geological Survey (USGS), Alaska Ocean Observing System (AOOS), and others will also be coordinated. NPRB has worked closely with the Interagency Arctic Research Policy Committee (IARPC) Chukchi and Beaufort Sea Ecosystem Collaboration Team and the U.S. Arctic Research Commission (USARC) to develop this highly-collaborative program.

In developing the broad direction for this program, recommendations provided by a wide variety of stakeholders and scientific experts were considered. A framework document authored by the IARPC Chukchi and Beaufort Sea Ecosystem Collaboration Team recommended broad research priorities that represent the consensus view of participating federal funding agencies (Wiese et al. 2015). A report summarizing the outcomes of a workshop organized by this collaboration team (Dickson 2014) provided more detailed recommendations, particularly on developing a conceptual model of the Arctic marine ecosystem. The Pacific Marine Arctic Regional Synthesis (PacMARS, http://pacmars.cbl.umces.edu/) provided detailed recommendations from the scientific community and included input from Alaska Native communities in the Bering Strait, Northwest Arctic, and North Slope regions of Alaska. Members of other stakeholder groups, including industry, environmental non-governmental organizations, and Alaska Native co-management organizations, were also consulted.

This program will involve the integration of multiple streams of marine data, from physical forcing factors to the processes driving marine ecology, human dimensions and consideration of ecosystem services. Success of the program will rely on careful coordination and effective collaboration. All participants will be expected to collaborate with colleagues outside of their specific discipline and innovate means of integrating data to achieve ecosystem-level understanding. NPRB will facilitate this through active program management, to include the organization of regular meetings of the participants, data management support, and close coordination with the program's steering committee (which will be established after proposals are selected for funding and will include representatives from each component of the funded program).

The NPRB-led program will be centered in the Chukchi Sea, but will also include the Bering Strait and northern Bering Sea, especially with respect to advective forcing. NPRB is interested in also including connections to the Beaufort Sea and Arctic Basin and encourages collaboration with programs such as the BOEM-funded Marine Arctic Ecosystem Study (MARES) and Russian-American Long-Term Census of the Arctic (RUSALCA). NPRB is also interested in integrating global-scale atmospheric and climate data and opportunities to facilitate comparisons between the Chukchi Sea and other marginal or regional seas throughout the Arctic.

NPRB plans to issue a solicitation for pre-proposals in spring 2015 and invitations for full proposals in fall 2015. Full proposals will be reviewed during winter 2015 and proposers will be notified of funding decisions in spring 2016. Some field sampling may proceed in fall 2016 if proposers leverage logistical resources already in place. Most field observations are anticipated to occur 2017-2019. At least two years of integrated analysis and synthesis will follow. Additional funding for synthesis may be provided for 2019-2021.

NPRB is committed to regularly communicating the research plans, intermediate progress, final results and management applications of the Arctic program to the broader scientific community, stakeholders, and the public. NPRB will dedicate resources to facilitating this communication. Program participants will be called upon to engage in outreach activities.

Coordination and collaboration will be essential to the success of this program and NPRB is interested in learning about new opportunities to collaborate throughout. Interested parties should contact the NPRB Arctic Program Manager at any point to discuss opportunities to participate.

II. Arctic Science

Ecosystem Context

NPRB defines the southern boundary of the Arctic Large Marine Ecosystem (LME) as Bering Strait and treats the Aleutian Islands/Bering Sea separately. The Arctic Program will adopt the southern boundary of the Chukchi LME as redefined by the Arctic Council PAME working group (PAME 2013) and will include the northern Bering Sea (above 61.5 ° N) as it influences dynamics in the Chukchi Sea, with greater focus on the Bering Strait and Chukchi Sea. The program will include the Arctic basin and Beaufort Sea insofar as processes in the Chukchi Sea are influenced by these adjacent areas. The program may also include analyses that scale to address pan-Arctic processes or comparisons with other Arctic marginal seas (see Hunt et al. 2013).

Physical Oceanography
The Chukchi Sea is a relatively shallow (~80 m) sea adjacent to the Arctic Ocean. Water generally flows northward from the Bering Sea through Bering Strait and northward across the Chukchi Sea shelf via topographically-steered currents. In the northern Chukchi Sea, two canyons run south to north (Barrow Canyon in the northeast, and Herald Canyon in the west). Hanna and Herald shoals in the northern Chukchi Sea split the northward flow of Bering Sea Water into three branches (Coachman et al. 1975, Woodgate et al. 2010). One branch flows east of Hanna Shoal and continues to Barrow Canyon, one flows west of Herald Shoal through Herald Canyon, and a third flows between the shoals via what is called the Central Channel.

Water in the Chukchi Sea is cold and well mixed from fall through spring as the sea remains ice-covered throughout the winter and inflow of warm water ceases (Woodgate et al., 2005b). Bering Sea Water represents the majority of the water entering the Chukchi Sea through the Bering Strait (> 80%) and is a mixture of nutrient-rich Anadyr Water from the west and Bering Shelf Water from the south (Coachman et al. 1975). Seasonally, relatively warm and moderately saline Bering Sea Water is advected northward and replaces cool, fresh surface waters and cold, dense winter water (Weingartner 2013; Arctic Ecosystem Integrated Survey 2014). This relatively warm water surpasses solar heating as the dominant source of heat flux in the system by September and may contribute to melting sea ice (Weingartner et al. 2013). Bering Sea Water is advected eastward from Central Channel and water properties and stratification patterns progress from west to east (Weingartner et al. 2013).

Synthesis of oceanographic data collected in the Bering Strait region since 1990 has provided important information about variability in the waters entering the Chukchi Sea. Water column properties in Bering Strait are strongly influenced by wind patterns and can vary significantly over very short (i.e., hourly) time scales (Woodgate et al. 2015). The volume of water flowing northward through the strait and heat transport have both increased since 2001 (Woodgate et al. 2010, Woodgate et al. 2012, Woodgate et al. 2015), and trends such as these could have significant impacts on sea ice dynamics and phenology of biological production.

Sea Ice

The Chukchi Sea is typically covered by sea ice November-May and ice retreat during spring is driven by increased solar radiation and advection of relatively warm water from the Bering Sea. According to the U.S. National Snow and Ice Data Center, Arctic sea ice has been declining at a rate of 13.3% per decade relative to the 1981 to 2010 average. Sea ice extent over the Arctic Ocean reaches a minimum in September and the ten lowest September ice extents over the satellite record have all occurred in the last ten years. Arctic sea ice extent reached a record minimum in September 2012, when it was 16 percent lower than any previous September since 1979, and 45 percent lower than the average ice extent 1981-2010. In several instances in recent years, sea ice has retreated off of the Chukchi Sea shelf completely in September. The prospect of increasing periods of open water in the late summer has implications for stratification, mixing, wave action, and nearshore erosion (Thomson and Rogers 2014).

Sea ice plays an important role for many species and ecological processes, and also protects the shore from wave action and erosion. It also provides a means for people to travel to places that are otherwise not accessible or only reachable by boat. Combined with the effects of changes in sea ice on species important for subsistence, rapid changes in the timing of sea ice presence or its extent and thickness will have profound influences on coastal communities.

Primary and secondary productivity

Sea ice algae provides an important source of primary production during the ice-covered period (Gradinger 2009). Pelagic primary production typically begins to occur as sea ice retreats and surface waters receive sufficient solar radiation. The location of the sea ice edge and the availability of sufficient nutrients will determine when and where the plankton blooms that will form the basis of the pelagic food web will originate, and significant changes in sea ice extent observed since 2005 may cause shifts in the phenology of production in this region (Grebmeier et al. 2015).

The PacMARS project reported that zooplankton, which represent important secondary producers, are not believed to be resident over the Chukchi Sea shelf throughout the ice-covered period and are instead advected northward from the Bering Sea, yet the authors acknowledged that very little information is available about the winter distribution of zooplankton in the Chukchi Sea (Grebmeier et al. 2015). Some zooplankton may enter the Chukchi Sea from the Arctic basin via upwelling along the shelfbreak.

The timing of sea ice retreat, onset of spring plankton blooms, and advection of secondary producers influences the pattern of pelagic-benthic coupling in the Chukchi Sea. Because the Chukchi Sea shelf is relatively shallow, pelagic production is exported to the benthos relatively quickly if it is not consumed. Changing patterns of sea ice retreat and strength of advection may cause mismatch in the phenology of production cycles. Such changes may cause cascading effects throughout the ecosystem, with implications for fish, seabirds and marine mammals. Changes in the availability of the subsistence species upon which humans rely might be expected coincident with changing patterns of primary and secondary productivity.

Benthos

Benthic biomass far exceeds pelagic biomass in the Chukchi Sea (Dunton et al., 2005, Moran et al. 2005, Grebmeier et al., 2006a Lepore et al. 2007, Campbell et al., 2009; Whitehouse 2014). The biodiversity of benthic communities varies in association with the origins of overlying water masses and sediment type. Biodiversity tends to increase with latitude in the Chukchi Sea due to the accumulation of fine-grain sediments that support benthic fauna and the availability of food resources in bottom water and surface sediments (Grebmeier and McRoy 1989, Feder et al. 1994).

The PacMARS project found that some areas of high benthic biomass (termed “hotspots”) persisted consistently over time, yet some important shifts were also identified (Grebmeier et al. 2015). In both the Chirikov Basin and the Chukchi Sea, benthic biomass distribution shifted northward in the period 2005-2012 as compared to the period prior to 2005, coincident with significant changes in summer sea ice extent. Such northward shifts in benthic biomass could be related to increasing export of pelagic biomass to the benthos as a result of increasing plankton production associated with the retreat of sea ice, changes in water chemistry, and/or stronger advection of water northward. The Distributed Biological Observatory sampling lines were established to monitor biological hotspots over time, and it is important to understand the mechanisms influencing shifts in biomass in order to properly interpret the time-series data collected by the DBO.

Fishes

Benthic and demersal fish are more abundant than pelagic species in the Chukchi Sea (Whitehouse 2014) with important differences in nearshore, shelf and basin habitats (Thedinga et al. 2013, Logerwell 2014; Lauth 2014). The most common fish families include cods (Gadidae), sculpins (Cottidae), eelpouts (Zoarcidae), and righteye flounders (Pleuronectidae) and dominant species include Arctic cod (*Boreogadus saida*), saffron cod (*Eleginus gracilis*), Arctic staghorn sculpin (*Gymnocanthus tricuspis*), shorthorn sculpin (*Myoxocephalus scorpius*), eelpouts (*Lycodes* spp.), and Bering flounder (*Hippoglossoides robustus*) (Norcross et al. 2013). Juvenile Arctic cod (*Boreogadus saida*) represent an important pelagic fish resource and appear as a dominant prey item in the diets of several seabird and marine mammal species (Lowry et al. 1980, Harter et al. 2013). Although Arctic cod appear to represent an important fish from an ecological perspective, basic information such as spawning timing and location is virtually unknown for this species.

Some fish species that inhabit the nearshore waters of the northeastern Chukchi Sea are typically missed by offshore fish trawls and are only sampled in gear like beach seines or fyke nets. For example, nearshore waters represent important habitat for age-0 and adult spawning capelin. Comparatively greater numbers of capelin were observed in years when water temperatures nearshore were warmer and, conversely, greater numbers of Arctic cod were observed nearshore when waters were cooler (Thedinga et al. 2013). Forage fish like capelin are prey for some subarctic baleen whales such as humpback and fin whales, which have been appearing more frequently in the Chukchi Sea in recent years (Clarke et al. 2013). Changing climate patterns may influence forage fish abundance and distribution, which in turn may influence the distribution patterns of the upper trophic level species that prey upon them.

Seabirds

Several birds occupy the region, many of which are seasonal migrants. In the northeast Chukchi Sea, a variety of birds may be observed seasonally, including loons, phalaropes, kittiwakes, gulls, terns, murres, auklets, murrelets, and shearwaters (Day et al. 2013). Arctic coastal lagoon systems, such as the barrier islands in the Chukchi Sea, are an important breeding habitat for waterfowl, gulls and some seabirds (Morse 2007). Overall, planktivorous seabirds (small auklets, *Aethia* spp.) and murres (*Uria* spp.) are the most abundant breeding seabirds in the Bering Strait and Chukchi Sea (USFWS, 2003) although in comparison to the Aleutian Island region, there are few birds along the shores of the Chukchi Sea, in part due to a lack of suitable nesting sites for cliff-nesting species. The area around St Lawrence Island supports the world population of the benthic feeding spectacled eider *(Somateria fischeri*), whose prey base has changed and is heavily influenced by patterns in sea ice and export to the benthos (Lovvorn et al. 2009, Larned et al. 2012).

Marine mammals

Marine mammals are important elements of the Arctic marine ecosystem, serving as apex predators and subsistence resources for local people. Most marine mammal species make seasonal migrations, generally following the edge of the sea ice. Many Arctic marine mammal species breed in the Bering Sea during winter and migrate northward to follow prey during summer (Wynne 1997). This is especially true for pelagic foragers such as bowhead and beluga whales, ringed, spotted, and ribbon seals, as well as polar bears, whose preferred prey include some of these marine mammal species. Some North Pacific species such as fin, minke, humpback, and killer whales have been observed in the Chukchi Sea following the retreat of the sea ice during late summer and fall, presumably to take advantage of seasonally abundant prey (Clarke et al. 2013). Common benthic foragers include walruses (*Odobenus rosmarus*), bearded seals (*Erignathus barbatus*), and gray whales (*Eschrichtius robustus*; Dehn et al. 2007; Highsmith et al. 2006), and bowhead whales (*Balaena mysticetus*) feed on epibenthic as well as pelagic prey (Moore et al. 2010). For bearded seals, the shallow eastern Bering and Chukchi Sea continental shelves represent the largest continuous expanse of their preferred habitat in the world (Burns and Frost 1979).

Bearded and ringed seals rely on sea ice during the breeding season, and limited tagging studies have provided evidence that both species exhibit breeding site fidelity (Kelly et al. 2010, Boveng and Cameron 2013). Ringed seals are particularly dependent upon sea ice for breeding because they give birth in snow caves (lairs) that they dig in sea ice (Furgal et al. 1996). Decreases in the availability of suitable sea ice during their breeding seasons may affect the breeding success these species.

The effects of decreases in sea ice availability have begun to affect the distribution of Arctic marine mammal species. Walruses generally haul out on sea ice close to important benthic foraging areas, however, in several instances since 2007, walruses have hauled out in large numbers along the coast of the northeast Chukchi Sea after sea ice has retreated off of the Chukchi Sea shelf (Jay et al. 2012). Observations of polar bears swimming long distances across open water have been recorded in recent years in late summer/early fall (Monnett and Gleason 2006, Durner et al. 2011). Shifts in the distribution of marine mammals may have ecological as well as social implications.

People and ecosystem services

Local people rely on marine mammals and myriad other species for subsistence. Subsistence accounts for a relatively large portion of the local economy in remote Alaska villages, and changes in the distribution or abundance of subsistence resources can have serious effects on food security as well as safety and culture. Marine mammals such as the bowhead whale, beluga whale, several species of ice-associated seals, and walruses are important economically, culturally, and spiritually. They provide important sources of food, raw materials for transportation, clothing and art, and foci for passing down knowledge, hunting skills, and ways of life. The harvest of marine mammals and other marine resources requires hunters to venture out onto the sea ice or out to sea in small boats. Changes in the distribution of those resources that may accompany changes in environmental conditions may also lead to more dangerous hunting conditions. Reduced sea ice cover typically results in greater fetch and higher seas. As the ice edge retreats, resources that are associated with the ice will move farther from shore, requiring hunters to travel farther over potentially more dangerous seas to harvest them.

Through better understanding the processes that affect the availability of subsistence resources it may be possible to predict shifts in advance and help local communities better prepare for change. If physical drivers that are easily monitored remotely can be used to predict shifts in ecological processes, then it may be possible to provide advance warning of such shifts that could affect local communities.

While Alaska Native communities have been surviving and adapting to change in the Arctic for thousands of years, the rapidity, breadth, and extent of recent changes present tremendous difficulty and expense. Some coastal villages such as Shishmaref and Kivalina are facing erosion problems that will likely require the village to be relocated. Ice cellars dug in the permafrost that are used to preserve food are thawing. Humans in the Bering Strait and Chukchi Sea coastal communities are a part of the marine ecosystem much like any other species. Their way of life will be affected by changes in the environment and adaptation is essential.

Local people have lived in coastal Arctic communities for centuries and have communicated lessons about ecological change and adaptation generation by generation through oral history. Local and Traditional Knowledge can provide current science context and can guide hypothesis-driven research. Furthermore, scientific investigations can be better designed with input from local people. Iterative exchange of information between marine scientists and people living in the region will improve our understanding of the ecosystem and humans' role in it.

Building on Existing Knowledge

Although there is a clear need for additional studies in order to better understand the processes driving the Arctic marine ecosystem, research has been ongoing in this region for several decades and any future research efforts should build on the information collected previously. Recognizing that, syntheses of Arctic marine data have been funded by a number of entities in recent years, including the Pacific Marine Arctic Regional Synthesis (PacMARS http://pacmars.cbl.umces.edu/), Synthesis of Arctic Research (SOAR http://www.arctic.noaa.gov/soar/), and a synthesis of the results of the Russian-American Long-Term Census of the Arctic (RUSALCA http://www.arctic.noaa.gov/aro/russian-american/).

Several special issue publications have been produced that report the results of multidisciplinary research programs, including those sponsored by industry and government. Among the most recent publications are "Seasonal and interannual dynamics of the northeastern Chukchi Sea Ecosystem" (Hopcroft and Day 2013), "The Northern Chukchi Sea Benthic Ecosystem: Characterization, Biogeochemistry, and Trophic Linkages" (Dunton et al. 2014), and "The Phytoplankton Megabloom beneath Arctic Sea Ice: Results from the ICESCAPE Program" (Arrigo 2014).

In recent years, several large research programs have collected data in waters of the Alaskan Arctic. BOEM's Alaska Region Environmental Studies Program (http://www.boem.gov/akstudies/) has provided many millions of research dollars in an effort to collect the environmental information necessary to consider permitting industrial activities. BOEM has also invested in social science research, including documenting traditional subsistence harvest patterns and recent changes. Beginning in 2008, Shell, ConocoPhillips, and Statoil jointly funded the multidisciplinary Chukchi Sea Environmental Studies Program (CSESP https://www.chukchiscience.com/) to collect baseline information in the northeast Chukchi Sea near oil and gas lease areas. The Office of Naval Research (ONR http://www.onr.navy.mil/), National Aeronautics and Space Administration (NASA www.nasa.gov), National Science Foundation (NSF www.nsf.gov), and other agencies have provided millions of dollars for Arctic sea ice and marine research as well. The NOAA Alaska Fisheries Science Center Resource Assessment and Conservation Engineering Division has conducted a series of bottom trawl surveys in the northern Bering Sea and Chukchi Sea (Lauth 2014) and nearshore surveys of marine taxa (Logerwell 2014) and the NOAA Alaska Fisheries Science Center Resource Ecology and Ecosystem Monitoring program has applied these data and ecosystem models to develop a mass-balance model of energy flow in the systems (Whitehouse 2014). The University of Alaska School of Fisheries and Ocean Sciences has also developed an Arctic Ecosystem Integrated Survey in the Chukchi Sea (https://web.sfos.uaf.edu/wordpress/arcticeis). NPRB has provided approximately $5 million for individual Arctic marine research projects and details about those projects can be found via the NPRB project browser (http://project.nprb.org/).

A substantial amount of data collection and integration has occurred to date, and many ongoing projects will provide essential pieces of information to help understand how the Arctic marine ecosystem functions. Integration and expansion upon existing datasets will assist in directing additional retrospective studies and future field observations. Arctic marine systems are in a period of rapid change (Wassman 2011). In addition to building on a baseline understanding of ecosystem structure and function, the NPRB program intends to provide further clarity on prominent mechanisms and interactions and to provide insight on how this system might change in the context of a changing climate.

III. Arctic Program

Arctic Program Scope

The NPRB-led Arctic Program is being developed with the following objectives in mind:

(1) Research will explore system processes and species dynamics relevant to ecosystem structure and function in Arctic marine systems, resource management, subsistence use, and human impacts.
(2) Research questions should be posed in the context of developing a mechanistic understanding of how physical processes (e.g., sea ice dynamics, advection patterns, seasonal patterns, winter conditions and seasonal reset) influence ecosystem structure and function, define temporal or spatial hotpots, influence relative shifts in benthic and pelagic systems, and influence the persistence, abundance, distribution, and life history of species or species guilds that are essential to ecosystem function or species that are important to subsistence users.
(3) Research should inform a baseline understanding of current processes as well as an understanding of how systems might shift in the context of a changing climate.

Geographic Focus

The NPRB Arctic Program will focus on the Chukchi Sea and will include Bering Strait and the northern Bering Sea. This area is of interest due to:

(1) the opportunity this region presents to examine the effects of changes in sea ice dynamics and the role of advection in structuring an Arctic ecosystem (research priorities recognized by the scientific research community, funding entities, and management agencies);
(2) a high demand from stakeholders;
(3) an emerging consensus among partners to leverage existing data and planned platforms to understand physical and ecological processes in this region;
(4) an intent to examine a cohesive system with a prominent set of physical attributes establishing boundaries to the area of interest (e.g., coastal shelf of the Chirkov/Chukchi); and
(5) the opportunity to further explore themes and questions that build on priorities articulated in the PacMARS Final Report and processes explored in the Bering Sea Project.

Spatial Scale

In developing an Arctic Program, funding partners aim to:

(1) structure research to inform or facilitate comparisons of mechanisms and processes relevant to areas not directly encompassed in the program, including the Beaufort Sea and Arctic Basin;
(2) encourage the development of analyses and models that can be scaled down to localized phenomena and up to regional/global scales (e.g., physical forcing and climate models);
(3) create opportunities for collaboration across the Chukchi Sea shelf with scientists and initiatives in Russia through existing mechanisms (e.g., RUSALCA) and enhance those collaborations and/or explore new mechanisms for collaboration with research conducted across the US/Russia maritime boundary in the western Chukchi Sea; and
(4) create opportunities to enable comparisons to other Arctic systems and research in Arctic regional seas (e.g., Barents Sea Nansen's Legacy Project).

Arctic Program Research Questions

The overarching questions that this program will address are the following:

How do physical, biological and ecological processes in the Chukchi Sea influence the distribution, life history, and interactions of species or species guilds critical to subsistence and ecosystem function? How might those processes change in the next fifty years?

The goal of the program is to better understand the mechanisms and processes that structure the ecosystem and influence the distribution, life history, and interactions of biological communities in the Chukchi Sea. NPRB is interested in research that addresses phenology and the alignment in space and time of primary production, secondary producers, and upper trophic level predators. NPRB is also interested in better understanding how mechanistic processes currently influence the ecosystem, and how they may change on the timescale of decades. The pelagic and benthic components of the Chukchi Sea ecosystem are strongly linked. While proposals that seek to elucidate processes or elements of either the benthic or pelagic components of the system alone will be considered, NPRB also encourages studies that address benthic-pelagic coupling. This program aims to produce a series of peer-reviewed scientific manuscripts and outreach materials to inform policy-makers and the interested public.

Proposals will be solicited in each of the following categories. Proposers must identify one category under which to compete. Ideally the program will include at least one project from each of categories 1 through 5 and will address both the pelagic and benthic components of the ecosystem.

NPRB intends to fund multiple proposals under each category. Target funding for each category is meant to serve as guidance. On the basis of proposals received or other considerations, the board may adjust the funding allocated to each category. Please note that the questions listed under each category are intended to direct applicants towards relevant questions. These questions are not prescriptive and applicants may address more than one.

Research Categories	**Target Funding**
1. Patterns in subsistence use and potential shifts in response to ecosystem change	$500,000
• What are local people’s perceptions of the natural physical and ecological drivers of changes in the availability of animals for subsistence harvest? Studies are sought that will a) achieve iterative exchange of information and relationship building between local people and scientists and b) develop processes and analytical methods that use local and traditional knowledge and western science in concert to achieve greater understanding of the system. • What are the primary drivers (natural, social, cultural, economic) of shifts in subsistence use patterns? Have shifts in harvest patterns affected food security and, if so, how? • How resilient are human communities to variability, anomalies, and shifts in the marine environment?	
2. Species distribution and interaction: Physical, biological and ecological drivers and important thresholds/tipping points relevant to the distribution and life history of apex predators, species importance to subsistence, and species or species guilds critical to ecosystem function	$2,500,000

• How are the distribution and life history of upper trophic predators (including those that represent important subsistence resources for local communities) influenced by changes in the abundance, density, location, and timing of lower trophic level resources (benthic and pelagic) and what are the mechanisms that determine the availability of lower trophic level resources? • What are the mechanisms that create and maintain biological hotspots? Are the primary drivers static (e.g., bathymetry, topography), and will these hotspots persist or shift? To what extent are hotspots associated with specific annual, seasonal, or finer-scale temporal fluctuations (e.g., hot-times)? Are benthic or pelagic hotspots related to areas where nutrient-rich winter water is retained on the shelf and, if so, what are the mechanisms that influence winter water retention? • How important are hotspots in maintaining the ecological structure of the ecosystem and to what degree do species or species guilds critical to ecosystem function or subsistence species rely on them? • Is the range of variability in key parameters observed at hotspots the same as the range of variability observed elsewhere? To what degree are patterns observed at hotspots representative of patterns in the broader ecosystem? • Does the structure and function of the Chukchi Sea ecosystem (in its current form) rely on one or more species (e.g., forage fish)? What are the species and why are they important? What ecosystem-level effects might we expect if these species were substantially reduced at local or system-wide geographic scales? • How sensitive and resilient are species to variability, anomalies, and shifts in the physical environment? Studies should focus on species or species guilds critical to ecosystem function or subsistence. • Do tipping points exist that could cause major shifts in distribution, population-level survival, or the role of species in this environment? Consider tipping points that go beyond trophic interactions (e.g., habitat requirements, association with sea ice). Studies should focus on species or species guilds critical to ecosystem function or subsistence.	
3. Oceanography and lower trophic level productivity: Influence of sea ice dynamics and advection on the phenology, magnitude and location of primary and secondary production, match-mismatch, benthic-pelagic coupling, and the influence of winter conditions	$2,750,000
• What are the mechanisms that determine the availability of lower trophic level resources? How will changes in the abundance, density, location, and timing of lower trophic level resources (benthic and pelagic) influence the distribution and life history of upper trophic predators, including those that provide important subsistence resources for local communities? • What are the rates of consumption, growth, reproduction, and mortality of secondary producers (benthic and pelagic) and to what extent are these rates limited by primary production, water properties, and other factors? • How do variation in the timing and location of sea ice breakup/retreat, the strength of advection, and the properties of advected water influence primary production patterns? What factors limit primary production in this system? How does stratification influence primary production, and how variable are stratification patterns in time (seasonally and inter-annually) and space?	

• Are changes in advective forcing over the Chukchi Sea shelf dominated by remote forcing (e.g., pressure fields in the Bering Sea that control flow through Bering Strait) or local conditions? What are the implications for our ability to predict flow patterns at various scales? • To what extent do winter conditions "reset" the Chukchi Sea ecosystem each year? Do anomalous summer conditions in a given year influence spring phenology the following year? Are the impacts of seasonal warming cumulative across years? What are the rates of consumption, reproduction, and survival of organisms during winter and how do they affect spring production? • How will changes in sea ice dynamics, strength and patterns of advection, and phenology of biological production influence pelagic-benthic coupling in the Chukchi Sea? What are the mechanisms that determine the partitioning of energy between the pelagic and benthic realms and how are they affected by changes in sea ice dynamics and advection? • Do thresholds exist that, if crossed, would cause significant shifts in the balance of energy between the pelagic and benthic components of the Chukchi Sea ecosystem? Is it possible to predict such shifts through monitoring key parameters and, if so, what are those parameters and on what scale (geographically and temporally) would observations be required?	
4. Modeling	$500,000
• NPRB may fund a fully-coupled ice-atmosphere-oceanography model that examines the feedbacks and interactions of processes relevant to each of these physical systems and improves understanding of the processes driving the ecology of the Chukchi Sea. To the extent possible, models should utilize field data collected by moorings in the Bering Strait and northeast Chukchi Sea and remotely-sensed sea ice data. • NPRB solicits proposals for modeling efforts that address questions related to interactions among the biological components of the system and interactions between biological components and physical drivers (e.g., nutrient-phytoplankton-zooplankton models that include sea ice algae; network modeling, multispecies models).	
5. Other areas of research that align with priorities 1-4 above	$500,000
• Proposals to conduct work that does not fit clearly within categories 1-4 above may be considered if a compelling case is made and if these proposals articulate specifically how the proposed work would align with the areas of research detailed above.	

Arctic Program Implementation

NPRB will issue a solicitation in partnership with North Pacific Marine Research Institute and will disburse funds provided by NPRB and partner organizations including BOEM Alaska Region and North Slope Borough/Shell Baseline Studies Program.

NPRB will play a central role in coordinating marine research in the Chukchi Sea region and will work closely with entities who have provided funds through separate mechanisms. Several projects that are already underway will join the collaboration, including projects funded by BOEM, NSF, North Slope Borough/Shell Baseline Studies Program, NOAA, USGS, AOOS, and others. In some cases, it may be possible for these funding organizations to amend the original awards/contracts for these projects to provide supplemental funding for collaborative activities, and PIs should approach their respective funding institutions to inquire about opportunities for in-kind support.

Participants will sign a statement certifying that they have read, understand, and agree to abide by a program management plan that will be written for this program specifically. The plan will clearly articulate the expectations for participants. For example, participants will be required to attend annual PI meetings that will facilitate exchange of information among disciplines and foster collaboration as well as logistic planning meetings prior to each coordinated field season. Data sharing among participants will also be required.

Steering Committee
A steering committee will be established that will include the lead PIs of each major component of the research program. Lead PIs of large collaborating projects will be expected to participate. The steering committee and NPRB program manager will meet monthly via teleconference and will be responsible for ensuring integration among the various components of the program. The steering committee will work closely with the NPRB program manager to resolve issues such as budget shortfalls, logistical constraints, or non-compliance by individual PIs as necessary. Steering committee members may also be expected to serve as the guest editors for special issue publications that will be developed to report the results of the program.

Meetings
The main purpose of the NPRB Arctic Program is to better understand the processes driving the structure and function of the Arctic marine ecosystem. In order to achieve process-level understanding, collaborators will meet early in the development of the program to agree on a set of common hypotheses that all participants will contribute to addressing.

Annual PI meetings will be organized by NPRB and all PIs and Co-PIs funded through the NPRB-NPMRI solicitation will be required to attend. Collaborators will be strongly encouraged to attend. These meetings will be essential in facilitating inter-disciplinary collaboration. Preliminary results will be reported and plans will be laid for publishing papers in the peer-reviewed literature that demonstrate the value of an interdisciplinary, ecosystem-based approach.

Prior to each coordinated field season, lead PIs from projects funded directly through the NPRB solicitation, as well as collaborating projects, will gather for a logistics planning and coordination meeting during late fall/early winter. These meetings will involve allocating available ship time among projects, coordinating needs for equipment and personnel, and designing sampling plans and protocols.

All program participants will be strongly encouraged to participate in monthly conference calls, during which, information will be exchanged among collaborators and programmatic updates will be provided. These calls will provide a regular means of communication between the program's steering committee and other participants. The NPRB program manager will organize and participate in these calls.

Data Management
Data management for the program will be handled by a contractor who has demonstrated the ability to facilitate data sharing and ensure that finalized data and metadata are archived permanently in relevant national databases and at NPRB. The contractor will establish a password-protected, internet-accessible portal for collaborators to use. It will be expected that data will be shared with collaborators immediately following collection and quality control (i.e., within six months of collection).

Progress Reports
Participants funded through the NPRB-NPMRI solicitation will be required to submit semi-annual progress reports (following a template provided by NPRB) that will include 1) a table illustrating timeline and milestones of the individual project, 2) report period progress, 3) preliminary results, 4) description of integration activity, 5) description of concerns about progress, 6) list of poster/oral presentations during reporting period, 7) description of education and outreach, 8) brief statement about progress status, and 9) table illustrating future workplan and data delivery. These reports will be submitted twice per year at intervals decided during the kick-off meeting. Program managers of collaborating projects will be encouraged to collect similar information from separately-funded projects to facilitate coordination.

Timeline for review and selection of proposals

Action	Tentative timeline
Call for pre-proposals released	May 20, 2015
Pre-proposal submission deadline	July 31, 2015
Invitations for full proposals issued	October 2015
Full proposal submission deadline	January 15, 2016
Proposers notified of funding decisions	May 2016
Initial meeting of Principal Investigators	June 2016
Initial sampling and data synthesis	June 2016
First coordinated field season	June 2017

IV. References

Arctic Ecosystem Integrated Survey. 2014. School of Fisheries and Ocean Sciences. http://web.sfos.uaf.edu

Arrigo, K.R. (Ed). 2014. The Phytoplankton Megabloom beneath Arctic Sea Ice: Results from the ICESCAPE Program. Deep Sea Research Part II 105:1-118.

Boveng, P.L. and M.F. Cameron. 2013. Pinniped movements and foraging: seasonal movements, habitat selection, foraging and haul-out behavior of adult bearded seals in the Chukchi Sea. Final Report, BOEM Report 2013-01150. Bureau of Ocean Energy Management, Alaska Outer Continental Shelf Region, Anchorage, Alaska, USA. 91 Pp + Appendix.

Burns, J.J. and K.J. Frost. 1979. Natural history and ecology of the bearded seal, *Erignathus barbatus*. Final Report. Outer Continental Shelf Environmental Assessment Program. Research Unit 230, Contract Number 02-5-022-53.

Campbell, R.G., E.B. Sherr, C.J. Ashjian, S. Plourde, B.F. Sherr, V. Hill, and D.A. Stockwell. 2009. Mesoplankton prey preference and grazing impact in the western Arctic Ocean. Deep Sea Research Part II 56: 1274-1289.

Clarke, J., K. Stafford, S.E. Moore, B. Rone, L. Aerts, and J. Crance. 2013. Subarctic cetaceans in the southern Chukchi Sea: Evidence of recovery or response to a changing ecosystem. Oceanography 26(4):136-149. http://dx.doi.org/10.5670/oceanog.2013.81

Coachman, L.K., K. Aagaard, and R.B. Tripp. 1975. Bering Strait: The Regional Physical Oceanography, University of Washington Press, Seattle.

Day, R.H., T.J. Weingartner, R.H. Hopcroft, L.A.M. Aerts, A.L. Blanchard, A.E. Gall, B.J. Gallaway, D.E. Hannay, B.A. Holladay, J.T. Mathis, B.L. Norcross, J.M. Questel, S.S. Wisdom. 2013. The offshore northeastern Chukchi Sea, Alaska: A complex high-latitude ecosystem. Continental Shelf Research. http://dx.doi.org/10.1016/j.csr.2013.02.002i.

Dehn, L., G. Sheffield, E. Follmann, L. Duffy, D. Thomas, T. O'Hara. 2007. Feeding ecology of phocid seals and some walrus in the Alaskan and Canadian Arctic as determined by stomach contents and stable isotope analysis. Polar Biology 30(2):167-181.

Dickson, D. (Ed). 2014. Developing a Conceptual Model of the Arctic Marine Ecosystem. Workshop report, North Pacific Research Board, Anchorage, AK.

Dunton, K.H., J.L. Goodall, S.V. Schonberg, J.C. Grebmeier, and D.R. Maidment. 2005. Multi-decadal synthesis of benthic–pelagic coupling in the western arctic: Role of cross-shelf advective processes. Deep Sea Research Part II 52:3462–3477.

Dunton, K.H., J.M. Grebmeier, and J.H. Trefry (Eds). 2014. The Northern Chukchi Sea Benthic Ecosystem: Characterization, Biogeochemistry, and Trophic Linkages. Deep Sea Research Part II: 102:1-164.

Durner, J.M., J.P. Whiteman, H.J. Harlow, S.C. Amstrup, E.V. Regehr, and M. Ben-David. 2011. Consequences of long-distance swimming and travel over deep-water pack ice for a female polar bear during a year of extreme sea ice retreat. Polar Biology 34(7):975-984.

Feder, H.M., A.S. Naidu, S.C. Jewett, M. Hamedi, W.R. Johnson, and T.E. Whitledge. 1994. The northeastern Chukchi Sea: Benthos-environmental interactions. Marine Ecology Progress Series 111:171-190.

Furgal, C.M., K.M. Kovacs, and S. Innes. 1996. Characteristics of ringed seal, *Phoca hispida*, subnivean structures and breeding habitat and their effects on predation. Canadian Journal of Zoology 74(5): 858-874.

Gradinger, R. 2009. Sea-ice algae: Major contributors to primary production and algal biomass in the Chukchi and Beaufort Seas during May/June 2002. Deep Sea Research Part II 56(17):1201-1212.

Grebmeier and McRoy 1989. Pelagic-benthic coupling on the shelf of the northern Bering and Chukchi Seas. III: Benthic food supply and carbon cycling. Marine Ecology Progress Series 53:79-91.

Grebmeier, J.M., L.W. Cooper, H.M. Feder, and B.I. Sirenko. 2006a. Ecosystem dynamics of the Pacific-influenced northern Bering and Chukchi seas in the Amerasian Arctic. Progress in Oceanography 71:331-361.

Grebmeier, J.M, L.W. Cooper, C.A. Ashjian, B.A. Bluhm, R.B. Campbell, K.E. Dunton, S. Moore, S. Okkonen, G. Sheffield, J. Trefry, and S.Y. Pasternak. 2015. Pacific Marine Arctic Regional Synthesis (PacMARS) Final Report, North Pacific Research Board. 259 pp.

Harter, B.B., K.H. Elliott, G.J. Divoky, and G.K. Davoren. 2013. Arctic Cod (Boreogadus saida) as prey: Fish length-energetics relationships in the Beaufort Sea and Hudson Bay. Arctic 66(2):191-196.

Highsmith R.C., K.O. Coyle, B.A. Bluhm, and B. Konar. 2006. Gray whales in the Bering and Chukchi seas. *In*: Estes J.A., D.P. DeMaster, D.F. Doak, T.M. Williams, and R.L. Brownell Jr (eds). Whales, whaling, and ocean ecosystems. University of California Press; Berkeley, CA. pp. 303–313.

Hopcroft, R.R. and R.H. Day (Eds). 2013. Seasonal and interannual dynamics of the northeastern Chukchi Sea Ecosystem. Continental Shelf Research 67:1-166.

Hunt, G.L, A.L. Blanchard, P. Boveng, P. Dalpadado, K. Drinkwater, L. Eisner, R.R. Hopcroft, K.M. Kovacs, B.L. Norcross, P. Renaud, M. Reigstad, M. Renner, H.R. Skjoldal, A. Whitehouse, and R.A. Woodgate. 2013. The Barents and Chukchi Seas: Comparison of the Arctic shelf ecosystems. Journal of Marine Systems 109-110:43-68.

Jay, C.V., A.S. Fischbach, and A.A. Kochnev. 2012. Walrus areas of use in the Chukchi Sea during sparse sea ice cover. Marine Ecology Progress Series 468:1-13.

Kelly, B.P., O.H. Badajos, M. Kunnasranta, J.R. Moran, M. Martinez-Bakker, D. Wartzok, and P. Boveng. 2010. Seasonal home ranges and fidelity to breeding sites among ringed seals. Polar Biology 33:1095-1109.

Larned W, K. Bollinger, and R. Stehn. 2012. Late winter population and distribution of Spectacled Eiders (*Somateria fischeri*) in the Bering Sea, 2009 & 2010. Unpublished Report, U.S. Fish and Wildlife Service, Migratory Bird Management Office, Anchorage, AK, 23 p.

Lauth, B. 2014. Longterm monitoring of the marine ecosystems in the Bering and Chukchi Seas. 2012 Chukchi Survey. NOAA Technical Memorandum NMFS-AFSC-272.
Lepore, K., S.B. Moran, J.M. Grebmeier, L.W. Cooper, C. Lalande, S. Maslowski, V, Hill, N.R. Bates, D.A. Hansell, J.T. Mathis, and R.P. Kelly. 2007. Seasonal and interannual changes in particulate organic carbon export and deposition in the Chukchi Sea. Journal of Geophysical Research 112, C10024.
Logerwell, L. 2014 SHELFZ: Shelf habitat and ecology of fish and zooplankton in the Chukchi Sea. NOAA Technical Memorandum NMFS-AFSC-280.
Lovvorn J.R., J.M. Grebmeier, L.W. Cooper, J.K. Bump, and S.E. Richman. 2009. Modeling marine protected areas for threatened eiders in a climatically changing Bering Sea. Ecological Applications 19:1596–1613.
Lowry, L.F., K.J. Frost, and J.J. Burns. 1980. Variability in the Diet of Ringed Seals, Phoca hispida, in Alaska. Canadian Journal of Fisheries and Aquatic Sciences 37(12):2254-2261.
Monnett, C. and J.S. Gleason. 2006. Observations of mortality associated with extended open-water swimming by polar bears in the Alaskan Beaufort Sea. Polar Biology 29(8):681-687.
Moore, S.E., J.C. George, G. Sheffield, J. Bacon, and C.J. Ashjian. 2010. Bowhead Whale Distribution and Feeding near Barrow, Alaska, in Late Summer 2005–06. Arctic 63(2):195-205.
Moran, S. B., R. P. Kelly, K. Hagstrom, J. N. Smith, J. M. Grebmeier, L. W. Cooper, G. F. Cota, J. J. Walsh, N. R. Bates, D. A. Hansell, W. Maslowski, R. P. Nelson, and S. Mulsow. 2005. Seasonal changes in POC export flux in the Chukchi Sea and implications for water column-benthic coupling in Arctic shelves. Deep Sea Research Part II 52:3427-3451.
Morse, J.A. 2007. Alaska's Arctic marine resource synthesis and preliminary conservation assessment for the Beaufort and Chukchi Seas. Audubon Alaska, November 2007, 57 pp.
Norcross, B. L., Holladay, B. A., Mecklenburg, C. W., 2013. Recent and historical distribution and ecology of demersal fishes in the Chukchi Sea Planning Area. Final Report to the Bureau of Ocean Energy Management, Alaska OCS Region, Anchorage, AK. 200 pp.
PAME. 2013. Large Marine Ecosystems (LMEs) of the Arctic area. Revision of the Arctic LME map 15th of May 2013. Second Edition. Arctic Council.
Thedinga, J.F., S.W. Johnson, A.D. Neff, C.A. Hoffman, and J.M. Maselko. 2013. Nearshore fish assemblages of the northeastern Chukchi Sea, Alaska. Arctic 66(3):257-268.
Thomson, J., and W.E. Rogers. 2014. Swell and the sea in the emerging Arctic Ocean. Geophysical Research Letters. 10.1002/2014GL059983.
U.S. Fish and Wildlife Service. 2003. Beringian Seabird Colony Catalog-computer database. U.S. Fish and Wildlife Service, Migratory Bird Management, Anchorage, Alaska, 99503.
Wassman, P. 2011 Arctic marine ecosystems in an era of rapid climate change. Progress in Oceanography 90: 1-17.
Weingartner, T., E. Dobbins, S. Danielson, P. Winsor, R. Potter, and H. Statscewich. 2013. Hydrographic variability over the northeastern Chukchi Sea shelf in summer-fall 2008–2010. Continental Shelf Research 67:5-22. http://dx.doi.org/10.1016/j.csr.2013.03.012i
Wiese, F., G. Auad, D. Williams, R. Merrick, M. Jeffries, B. Kelly, A. Thornhill, L. Thorsteinson, and D. Dickson. 2015. Framing Arctic marine research initiatives: Framework for coordinated marine ecosystem research in the U.S. Chukchi and Beaufort Seas. North Pacific Research Board, Anchorage, AK.
Whitehouse, G.A. 2014. Preliminary mass-balance food web model of the Eastern Chukchi Sea. NOAA Technical Memorandum NMFS-AFSC-262.
Woodgate, R.A., K. Aagaard, J.H. Swift, K.K. Falkner, and W.M. Smethie. 2005a. Pacific ventilation of the Arctic Ocean's lower halocline by upwelling and diapycnal mixing over the continental margin. Geophysical Research Letters 32, L18609, doi: 10.1029/2005GL023999.

Woodgate, R.A., K. Aagaard, and T.J. Weingartner. 2005b. A year in the physical oceanography of the Chukchi Sea: Moored measurements from autumn 1990-1991. Deep Sea Research Part II 52: 3116-3149.
Woodgate, R.A., T.J. Weingartner, and R.W. Lindsay. 2010. The 2007 Bering Strait Oceanic Heat Flux and anomalous Arctic Sea-ice Retreat. Geophysical Research Letters 37, L01602, doi: 10.1029/2009GL041621.
Woodgate, R. A., T. J. Weingartner, and R. Lindsay. 2012. Observed increases in Bering Strait oceanic fluxes from the Pacific to the Arctic from 2001 to 2011 and their impacts on the Arctic Ocean water column. Geophysical Research Letters 39, L24603, doi:10.1029/2012GL054092.
Woodgate, R.A., K.M. Stafford, and F.G. Prahl. 2015. A Synthesis of Year-round Interdisciplinary Mooring Measurements in the Bering Strait (1990-2014) and the RUSALCA years (2004-2011). submitted to Oceanography, February 2015. http://psc.apl.washington.edu/BeringStrait.html.
Wynne, K. 1997. Guide to Marine Mammals of Alaska. Alaska Sea Grant College Program; 2nd edition. Fairbanks: Elmer. ISBN 978-1566120449, 80p.