Regional Action Plan for the Chukchi and Beaufort Seas

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Executive Summary

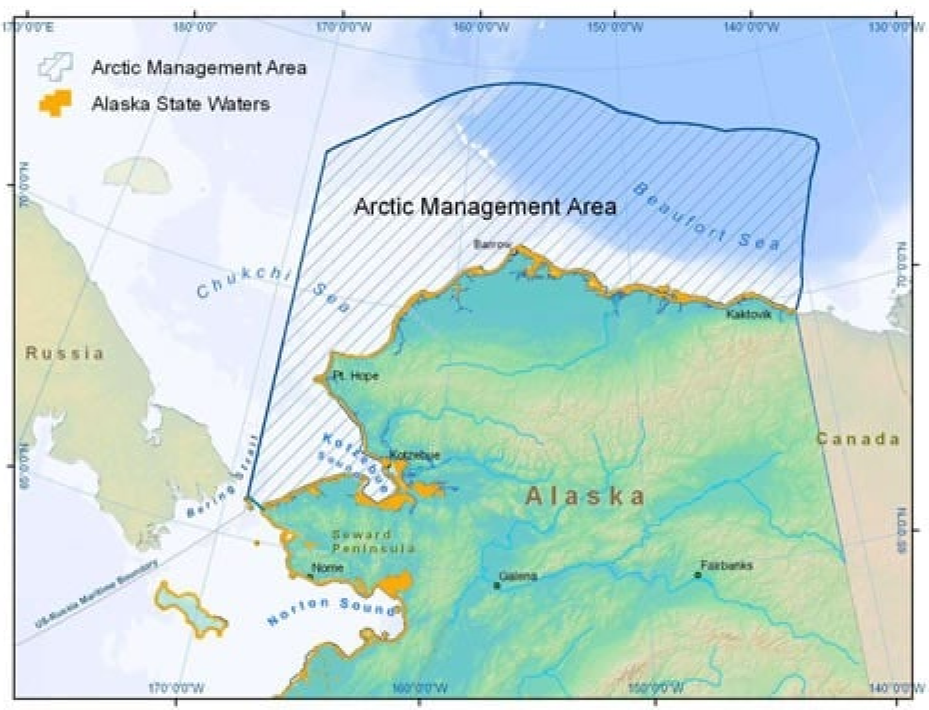
Climate change in the Chukchi and Beaufort Seas are driving rapid decreases in summertime sea-ice extent, resulting in (among other things): poleward movement of commercial fishes from the adjacent Bering Sea ecosystem; changes in migratory phenology and distribution for bowhead and beluga whales; impacted opportunities for subsistence hunting by Alaska Native communities; and likely shifts in pelagic-benthic coupling and resulting ecosystem productivity. We first seek to inventory previous ecosystem monitoring and synthesis programs. We then envision future coordinated activities regarding five types of research that involve the Alaska Fisheries Science Center: Monitoring; process research; management-oriented synthesis efforts; marine mammals; and socio-economics. Our inventory stresses the importance of eleven ongoing and expanded research activities. This includes four foundational activities to improve collaboration and communication with Alaska Native communities, as well as refreshing the Arctic Ecosystem Status Report to improve timeliness of communication with the North Pacific Fishery Management Council. It also includes studies to synthesize information about ice-seal consumption and include this in trophic models for the Chukchi and Beaufort Seas, laboratory experiments to understand overwinter survival for gadids, and using satellites to monitor Harmful Algal Blooms and demersal food for crabs. Finally, it includes focused expansion of the Distributed Biological Observatory and acoustic and field-based sampling for cetaceans. We also outline a proposed cross-program expedition to sample midwater and larger demersal fishes to measure ongoing and rapid changes in abundance and distribution. Collectively, we define a vision for how these eleven research activities will improve our capacity to detect and respond to future Arctic ecosystem changes.

Introduction

Polar Amplification results in greater changes in atmospheric temperatures than temperate or tropical regions given increased greenhouse gas concentrations, and this has resulted in declining summertime sea ice throughout Arctic large marine ecosystems (LMEs) including the Beaufort and Chukchi Seas. Human impacts on global climate are driving changes in spatial distribution and productivity for fishes and marine mammals worldwide and in the Arctic in particular, with resulting impacts on human livelihoods and subsistence.

The North Pacific Fishery Management Council (NPFMC) defines a Fishery Management Plan for the Fish Resources of the Arctic Management Area ("Arctic Fishery Management Plan" in the following) for the US Exclusive Economic Zone ("EEZ") of the Beaufort and Chukchi Seas, and we here use these same geographic boundaries to define the Arctic Regional Action Plan ("Arctic RAP"). The NPFMC developed the Arctic Fishery Management Plan in 2009. This plan prohibits commercial fishing (excluding salmon and halibut) "until sufficient information is available to support the sustainable management of a commercial fishery" (NPFMC 2009).

Fig. 1 -- Area defined for the Arctic RAP (using figure developed for the Arctic FMP, from https://www.npfmc.org/arctic-fishery-management/), where the US EEZ does not include Alaska state waters (orange shading) and is restricted to offshore waters (hatched blue lines).



The Arctic Council was formed by the Ottawa Declaration in 1996, and represents intergovernmental coordination of eight member states and numerous Permanent Participants. We note that the Arctic Council defines an LME that includes the northern Bering Sea as well as the Chukchi Sea (including US and Russian waters); we have instead restricted the Arctic RAP to Beaufort and Chukchi Seas to maintain consistency with the NPFMC.

In this Arctic Regional Action Plan, we seek to inventory past and present research, and recommend future research that will result in improved understanding, prediction, and management responses to coupled ecological and social system changes associated with ongoing climate changes in the US Beaufort and Chukchi Seas. Recommendations were developed based upon input from representatives of all AFSC programs, as synthesized by a steering committee from which the authors are drawn. We envision a targeted portfolio of monitoring, process research and synthesis efforts including lower trophic, fish, marine mammal, and human components of the ecosystem that would occur from 2022-2024. We specifically envision developing a collaborative research environment in which discussions and partnerships with Alaska Natives communities is a central element, so that the next Arctic Regional Action Plan can involve components that are co-produced with Alaska Native communities.

Chukchi Sea

The Chukchi Sea is a broad, relatively shallow (0-50m depth) shelf punctuated by canyons and shoals. Sea ice covers the Chukchi sea each winter, and by late summer, sea ice retreats and open water occurs over most of the shelf. There is very high interannual variability in sea ice extent and timing of retreat. The timing of seasonal sea ice retreat has important impacts on the Chukchi Sea ecosystem. The typical timing of seasonal ice melt and onset of stratification coupled with nutrient-rich waters results in early spring blooms with little pelagic grazing such that a large amount of in situ and advected pelagic production sinks to the seafloor supporting a diverse and biomass rich benthic community.

This rich benthic community in turn supports benthic foraging marine mammals such as walrus, bearded seals and gray whales; and seabirds such as eider. Despite high benthic productivity, fish populations and body sizes in the Chukchi Sea are small compared to the SE Bering Sea (and Barents Sea in the Atlantic) which support large commercial fisheries. It has been hypothesized that with ocean warming, reductions in sea ice and earlier retreat, blooms will occur later and more pelagic production will be consumed by the pelagic food web with less being exported to the benthos.

Another key characteristic of the region is the substantial and increasing flux of waters northward from the Bering Sea and Gulf of Anadyr through the Bering Strait (Woodgate et al. 2015). This results in a seasonal advection of nutrients, algal production, organic carbon, zooplankton, and pelagic fishes. While Bering Shelf Waters and Anadyr Waters mix within and downstream of Bering Strait, a strong density front typically separates the Alaska Coastal Water from the offshore waters both in the Bering Sea and farther north. The Alaska Coastal Water contrasts from offshore waters in that it is warm, has relatively low salinity and is nutrient-poor.

Beaufort Sea

The Beaufort Sea includes a narrow nearshore shelf in the west that widens to the east and is connected to deep offshore basins via a relatively steep slope. Oceanographically, the region is influenced by warm nutrient-rich waters that flow eastward from the Chukchi Sea, the Beaufort Gyre, and freshwater input primarily from the Mackenzie River that impacts surface water salinity and stratification. Cross-shelf exchange via upwelling and eddies can bring deeper waters such as Atlantic origin water, nutrients, and organisms onto the shelf. Variation in water mass composition and origin affects temperature, salinity, stratification, and biological communities in the basin and on the shelf. Ice cover is seasonal, and summer sea ice has declined in recent decades. Rapid shifts in sea ice are strongly influenced by wind speed and direction, with increased easterly winds advecting sea ice out of the region. Changes in sea ice also impact wind-forced seasonal upwelling along the shelf break.

Distributions and abundance of biota in the Beaufort Sea are impacted by interactions between wind, sea ice cover, cross-shelf exchange and upwelling as well as the diversity of nearshore, slope, and offshore habitats. Distributions of zooplankton and the prevalence of lipid-rich Arctic taxa that are important prey for higher trophic levels are impacted by temperature, salinity, and water mass origin. Arctic cod are the dominant component of the fish community and utilize multiple habitat types that differ across life stages, including larger adult individuals in high densities in deeper slope environments. Prevalent nearshore lagoons are also important habitats for salmon, saffron cod, and several forage fish species that are nodal Arctic food web components. [ADD 1-2 SENTENCES ABOUT BENTHIC COMMUNITY AND PRODUCTION]

Arctic cod, euphausiids, and lipid-rich copepods support substantial populations of bowhead whales, pinnipeds, and belugas. Marine mammals are often concentrated at hotspots such as the western Beaufort shelf near Point Barrow where oceanographic conditions aggregate copepods and euphausiids. This region also coincides with hotspots for some seabird species such as shearwaters. Changes in productivity caused by loss of sea ice, and associated increases in upwelling during the summer foraging season have been linked with increased body condition for bowhead whales in Beaufort Sea (George et al. 2015). Such linkages between marine mammal hotspots and changes in sea ice, shifts in upwelling, and oceanographic conditions suggest that climate change and ongoing loss of sea ice will impact distributions and abundance of multiple trophic levels with ecosystem and food security implications.

NOAA Fisheries Climate Science Strategy

The NOAA Fisheries Climate Science Strategy (Abrams et al. 2015) envisions seven questions and associated objectives:

1. Objective 1: Identify appropriate, climate-informed reference points for managing living marine resources (LMRs).
2. Objective 2: Identify robust strategies for managing LMRs under changing climate conditions
3. Objective 3: Design adaptive decision processes that can incorporate and respond to changing climate conditions.
4. Objective 4: Identify future states of marine and coastal ecosystems, LMRs, and LMR - dependent human communities in a changing climate
5. Objective 5: Identify the mechanisms of climate impacts on ecosystems, LMRs, and LMR-dependent human communities
6. Objective 6: Track trends in ecosystems, LMRs and LMR-dependent human communities and provide early warning of change.
7. Objective 7: Build and maintain the science infrastructure needed to fulfill NOAA Fisheries mandates with changing climate conditions

This Climate Science Strategy is implemented regionally through RAPs, of which this document is one such plan.

The AFSC has decided to organize this RAP by identifying future activities corresponding to five types of research:

- Monitoring (repeated, ongoing sampling via field-work and remote sensing)

- Process research (hypothesis-driven tests of biological processes using manipulative experiments and field observations)
- Management-oriented synthesis efforts (modelling or otherwise)
- Marine mammals
- Socio-economics

Alaska Regional Office Climate Information Needs and Priorities

The Alaska Regional Office (AKRO), which oversees the science-based stewardship of living marine resources and their habitat in the Arctic, relies on climate science information to support its stewardship mandate, including for work by its Sustainable Fisheries, Protected Resources, and Habitat Conservation Divisions (SFD, PRD, and HCD, respectively). In the Habitat Conservation Division, climate research products from activities in the Arctic are used both to delineate and inform the conservation of Essential Fish Habitat (EFH). In particular, monitoring, process studies, and management-oriented synthesis themed projects in the Chukchi and Beaufort Seas directly inform HCD activities, including the development of species distribution models and EFH geospatial products; projecting the effects of climate change on species distribution and EFH; the species and ecosystem monitoring to underpin those research efforts; and the design of climate-informed conservation recommendations to minimize adverse effects to EFH in the Arctic. SFD leverages strategic partnerships and prioritizes work to create climate-ready science and policy to address the management needs for Alaska fisheries, fishery dependent communities, and Alaska Natives who rely on ocean resources. SFD continues to support the AFSC's efforts to learn more about this area and be responsive to specific data and management needs related to climate-forcing events. PRD uses climate data from the Arctic to inform decisions for ESA-listings, critical habitat designations and Section 7 consultations. PRD takes climate data into consideration when evaluating stock status, status of a species, and expected impacts upon protected species. Because many protected marine mammals are highly ice-associated, climate change data are especially important in management of these Arctic species. The AKRO’s climate information needs in the Arctic span a range of stewardship objectives, and are supported by the research projects described in this Regional Action Plan.

Vision for how activities will respond to NMFS climate mandate

We envision eleven complementary research activities that will substantially strengthen the capacity for the National Marine Fisheries Service (“NMFS”), the NPFMC, Alaska Native tribes, as well as other local and national stakeholders to understand, forecast, and respond to ongoing and rapid climate changes in the Chukchi and Beaufort Seas.

Specifically, we believe that the Alaska Fisheries Science Center (AFSC) needs to improve its communications and collaborations regarding climate impacts affecting Arctic ecosystems. In particular, we envision promoting regular and reliable communications with Alaska Native tribes (“*Communications To Support Co-Producing Science with Arctic Communities*”), both (1) to facilitate access to (and benefits arising from) from science occurring in waters near tribal members, elders, and organizations, and (2) to facilitate AFSC scientists learning from and collaborating with community members that have long-term experience with the region. Communications would also be improved by developing and identifying members for a new taskforce including AFSC and Alaska Native representatives (“*Local Knowledge, Traditional Knowledge, and Subsistence Taskforce for Arctic Region*”), and collaborating to develop Indigenous Conceptual Models (“*Bridging Knowledge to Inform Arctic Management*”). We also recommend refreshing the previous Arctic Ecosystem Status Report ("*Arctic Ecosystem Status Report*"), to regularly communicate Arctic science with the NPFMC. These communications and collaborations are foundational for any successful science and management in the high Arctic.

In support of these improved communications and collaborations, we highlight several research activities to understand current and future climate conditions in the US high Arctic. This includes efforts to use satellites and focused process research to monitor lower-trophic processes affecting Harmful Algal Blooms (HABs) and food available for demersal crabs ("*Predicting HABs and juvenile snow crab status using satellite-based ocean color*"), as well as process research to understand prospects for overwinter survival for Pacific cod and walleye pollock ("*Overwinter survival for Arctic gadids*"). It also includes a synthesis of ice-seal consumption of fishes and benthic resources ("*The trophic roles of ice seals in Chukchi and Beaufort seas*"), which would then be included in trophic models for ecosystem productivity in these ecosystems ("*Expand Trophic and Spatial Models for Arctic Ecosystem*"). We also note the importance for ongoing passive acoustic and field-based sampling of cetaceans ("*Cetacean sampling in the Chukchi Sea*"), as well as expanded sampling of demersal communities within the Distributed Biological Observatory ("*Focused involvement regarding demersal communities within the Distributed Biological Observatory*").

Finally, we envision an exploratory survey of the Chukchi Sea for fishes and decapod crabs that are fished in the Bering Sea. This survey would include both large-mesh bottom trawl and acoustic-midwater trawl gears on a single vessel, and would update bottom-trawl sampling last conducted in 2012.

Inventory of past and present research activities

We here note some of the previous and ongoing research activities in the waters covered by this Arctic RAP, including Russian-American Long-Term Census of the Arctic (RUSALCA), the Arctic Integrated Ecosystem Research Program (AIERP), the Distributed Biological Observatory (DBO), as well as targeted studies for cetaceans and ice-associated seals. We briefly inventory these activities below.

RUSALCA

The Russian-American Long-term Census of the Arctic (RUSALCA) program stemmed from the 2003 Memorandum of Understanding between NOAA and the Russian Academy of Sciences (Crane and Ostrovskiy 2015). The program involved scientists from both countries carrying out the multidisciplinary research and observations needed to build a long-term climate and ecosystem observing network in the Pacific Arctic. The first expedition to the Bering and Chukchi seas was conducted in summer-early fall 2004. Expeditions continued until 2014. Sampling at stations included water column temperature, salinity, nutrients, chlorophyll and CO2; zooplankton and ichthyoplankton; benthic fauna; and sediment chemistry, chlorophyll and physical composition. In addition, moorings collected data on fluxes, biooptics, nutrients and ocean acidification; as well as passive acoustic monitoring of marine mammals. A 2015 special issue of Oceanography documented many of the key findings of the RUSALCA surveys (Crane and Ostrovsky, 2015).

DBO

The DBO is envisioned as a set of fixed transects designed to monitor biophysical responses in four pivotal geographic areas that exhibit high productivity, biomass, biodiversity, and rates of change (Grebmeier et al 2010). These areas are: the northern Bering Sea, the Bering Strait and southeastern Chukchi Sea, the central Chukchi Sea, the Barrow Arc and the Beaufort Sea. Measurements at transect sites include hydrography (temperature, salinity, nutrients, chlorophyll); and biomass, and species composition, as well as the size and condition of key organisms of phytoplankton, ichthyoplankton, and benthic fauna. Seabirds are assessed via standard visual surveys on ship transects and through indicator colony studies. Similarly, marine mammal visual and passive acoustic sampling are conducted on shipboard operations and on ocean observation moorings, respectively. Oceanographic moorings near and within the DBO transects measure water column properties and fluxes. Finally, coastal residents who subsist on fish, seabirds, and marine mammals contribute observations and tissue samples so that shifts in ice conditions, species diet, and contaminant levels can be tracked in higher trophic organisms. The DBO stations are occupied by Canadian, Chinese, Korean, Japanese, Russian, and U.S. research vessels currently being coordinated through the international Pacific Arctic Group (PAG), a network of governments and scientists working in the Pacific Arctic sector. The DBO sampling framework was initially tested during a 2010 Pilot Study, and DBO surveys continue to the present. See https://www.pmel.noaa.gov/dbo/ for maps of DBO stations and moorings, cruise data, publications and contacts.

Arctic EIS/IES: Integrated Ecosystem surveys of the Northern Bering-Chukchi Sea

The overarching goals of these programs were to better understand the mechanisms and processes that structure the Pacific Arctic marine ecosystem and to evaluate the potential effect of climate change on fish, marine mammals, seabirds and human communities. These goals were addressed with comprehensive assessments of the Northern Bering-Chukchi Sea conducted by multidisciplinary teams comprised of physical and biological oceanographers, fisheries scientists, marine ornithologists, marine mammalogists, social scientists, and Alaska Native communities.

Phase I, known as Eis, the Arctic Ecosystem Integrated Survey was funded by BOEM, the state of Alaska Coastal Impact Assessment Program and NOAA. The lead institution was the University of Alaska Fairbanks (UAF). AFSC EMA, GAP, MACE, and HEPR programs were co-leads. Surveys were conducted in late summer-fall in 2012 and 2013. A grid of stations from 60 N (Nunivak Island) to the slope of the Central Arctic Ocean was sampled for water mass characteristics (temperature, salinity), nutrient concentrations and phytoplankton biomass. To assess biological resources, surveys used:

1. Small and large-mesh bottom trawls for benthic fish and invertebrates (in 2012 only);
2. surface trawls for juvenile salmon and forage fishes;
3. plankton nets for zooplankton and larval fish;
4. acoustic-trawl surveys for gadids and forage fish; and
5. Visual observations of seabirds along the ship's track.

This effort provides a valuable baseline that could be repeated to demonstrate changes relative to 2012 (Mueter et al. 2017).

Phase II was renamed IES, Integrated Ecosystem Survey (to avoid confusion with NEPA's EIS Environmental Impact Statement). This project was funded by NPRB's Arctic Integrated Ecosystem Research Program (AIERP), the Collaborative Alaskan Arctic Studies Program, the Bureau of Ocean Energy Management (BOEM), the Office of Naval Research Marine Mammals and Biology Program, NOAA and UAF. The grid of stations established during Phase I was sampled again in fall-summer 2017 and 2019 for oceanographic characteristics and biological resources as described above. Only stations north of Bering Strait were sampled. In addition, several DBO transects were sampled and oceanographic, bottom-moored echosounders, and marine mammal passive acoustic moorings were recovered and deployed.

Also part of AIERP was the Arctic Shelf Growth Advection Respiration Deposition Rate survey (ASGARD), led by University of Alaska Fairbanks. Surveys of the northern Bering Sea to the southern Chukchi Sea were conducted in late May-early June in 2017 and 2018. Transects from St. Lawrence Island to Cape Lisburne were sampled for oceanographic characteristics, zooplankton, larval fish, epibenthic fish and invertebrates, and benthic infauna. In addition, onboard incubations were conducted to measure growth, respiration and deposition rates of phytoplankton and zooplankton. Oceanographic and marine mammal passive acoustic moorings were recovered and deployed.

The social science component of AIERP was conducted by a team that included Principal Investigators from the North Slope and Northwest Arctic Boroughs and the Bering Strait region. The goal was to develop meaningful interaction with Alaska Native communities to explore changing patterns of access to subsistence resources and food security.

Monitoring for cetaceans

The AFSC has previously conducted aerial surveys of bowhead and beluga whale abundance as part of the Aerial Surveys for Arctic Marine Mammals through an interagency agreement with BOEM. This survey was conducted over many decades but was ended in 2019 due to changes in priorities at BOEM. The most recent aerial survey included a modified survey design to assess bowhead whale abundance needed for International Whaling Commission (IWC) to determine allowable take levels for Alaska Native communities.

The AFSC uses passive acoustics deployed on moorings to detect year-round occurrence of marine mammals at 9 stations in the Chukchi and Beaufort Seas. Recordings are co-located on oceanographic moorings, which provides a decade-long time-series of information on marine mammal occurrence and oceanographic conditions. The recorders routinely capture sounds from 10 marine species, including the endangered bowhead and fin whales, and can inform how occurence is changing as sea ice conditions change.

Monitoring for ice-associated seals

Aerial surveys for bearded, ringed, spotted and ribbon seals were completed throughout their breeding ranges in Alaska waters of the Bering Sea (2012 - 2013), Chukchi Sea (2016), and Beaufort Sea (2021). The surveys provided the basis for the first comprehensive estimates of abundance for these species in Alaska waters. The survey and analytical methods are viable for regular and more frequent monitoring to quantify population trends, intended for 2023 in the Bering Sea, 2025 in the Chukchi Sea, and 2027 in the Beaufort Sea.

In addition to abundance and trend monitoring for seals, AFSC has sampled and satellite-tracked spotted, ribbon, and bearded seals to determine their haul-out timing (a key element of abundance estimates), monitor their body condition, characterize their habitat requirements and diet, and screen for exposure to pathogens. The primary effort, involving ribbon and spotted seals, has been conducted from a NOAA vessel 6 times between 2007 and 2018, and is intended to continue biennially.

Other focused efforts

We also note several previous or ongoing efforts with specific research and sampling foci. This includes:

- Focused sampling in the Beaufort Sea in 2008. Dominant benthic taxa, such as Arctic cod and snow crab were associated with cold, high salinity and presumably highly productive water offshore of the shelf break (Logerwell et al. 2011)
- The Shelf Habitat and Ecology of Fish and Zooplankton with sampling focused in the area of Barrow Canyon in 2013. Arctic cod were more abundant in deep, cold and highly saline water in Barrow Canyon, which was likely advected from the Chukchi Shelf or from the Arctic Basin and carried energy-rich copepods (Logerwell et al. 2018)
- Uncrewed surface vehicles were used in 2018 to conduct repeat acoustic surveys of the Chukchi shelf to study the seasonal movements of the abundant population of age-0 gadids. The surveys and transport models indicate that age-0 gadids are advected to the Chukchi shelf from the northern Bering Sea, are retained on the shelf during a period of growth until late fall, and are then advected farther north toward the Chukchi and Beaufort shelf breaks by fall (Levine et al. 2021).
- The Climate and Fisheries Initiative (CFI) is anticipated to be included in updates to NOAA funding during 2022-2024. If it proceeds as anticipated, this will provide a new MOM6 model for ocean physics and lower-trophic processes available for the central Arctic and adjacent oceans, including the Beaufort and Chukchi Seas.

These efforts generated samples of food habits for individuals captured in beam trawls, as well as other environmental and lower-trophic samples and associated decadal forecasts.

Action Plan for proposed activities

We recommend completing the following eleven primary activities over the next three years. Where possible, we list Specific, Measurable, Achievable, Relevant, and Time-Bound (SMART) metrics for success in each activity. We summarize these activities including how they correspond to five research types and the seven NCFSS objective (Table 1), and then described them in detail below.

Table 1 -- A summary of eleven proposed activities, including the primary research activities addressed (from Monitoring, Process research, Management-oriented synthesis, Marine mammals, Socio-economics), as well as 1-4 numbered goals that can be evaluated for progress prior to any further update of the Arctic RAP.

Number	Name	Research type	NCFSS objective
1	Bridging Knowledge to Inform Arctic Management 1. Promote interdisciplinary partnerships; 2. Develop Indigenous Conceptual Models; 3. Document collaborative methods.	Socio-economics	2
2	Communications To Support Co-Producing Science with Arctic Communities 1. Conduct radio interviews and local newspaper features; 2. Develop educational efforts targeting students, teachers and parents in the communities. 3. Use NMFS communications platforms to highlight collaborative efforts	Socio-economics	2
3	Predicting HABs and juvenile snow crab status using satellite-based measurements of ocean color 1. Develop a phytoplankton community size structure algorithm, 2. Advance a specific algorithm for the detection of small photosynthetic bacteria (*Synechococcus*), 3. Develop an algorithm for diatom abundance and	Process research	5

	4. Explore satellite metrics to predict HAB prevalence and juvenile crab abundance		
4	Renew Arctic ecosystem status report 1. Update the Arctic ESR during 2022-2024	Management-oriented synthesis	1, 3, 6
5	Cetacean sampling in the Chukchi Sea 1. Maintain and improve passive acoustics; 2. Develop and implement vessel and/or aerial survey	Marine mammals	6
6	Overwinter survival of Arctic gadids 1. Predict impact of summing warming on juvenile condition 2. Predict impact of condition on overwinter survival	Process research	5
7	Expand Trophic and Spatial Models for Arctic Ecosystem 1. Update Chukchi food web model 2. Develop Beaufort food web model 3. Compare system-level optimum yield across all Alaska ecosystems 4. Spatio-temporal synthesis model for survey planning:	Management-oriented synthesis	1, 3, 4
8	The trophic roles of ice seals in Chukchi and Beaufort seas 1. Estimate seasonal prey requirements 2. Expand to total ice-seal consumption	Marine mammals	1
9	Focused involvement regarding demersal communities within the Distributed Biological Observatory 1. Add beam trawls 2. Extend exploratory large-mesh trawling 3. Add benthic respirometer *4.* Add environmental DNA	Monitoring	6

10	Local Knowledge, Traditional Knowledge, and Subsistence Taskforce for Arctic Region 1. Convene Arctic LKTKS Task force	Socio-economics	3
11	Bottom trawl and acoustic-trawl survey to detect northward distribution shifts 1. Develop survey design 2. Conduct short gear trial 3. Implement combined sampling effort	Monitoring	7

Bridging Knowledge to Inform Arctic Management

The Arctic is undergoing rapid and unprecedented ecological and social changes, requiring innovative management strategies. Marine resources are critical to Alaskan communities for economic livelihood, food security, social cohesion, and cultural continuity. Alaska Natives have enduring historical, social, and ecological ties to their environment, and have extensive Traditional Knowledge (TK) on the Arctic ecosystem, which can provide current and historically-informed information to advance ecosystem-based management (EBM) and improve management decisions. Collaborative research bridging western science and TK will strengthen understanding to inform management of the Arctic, in accordance with Executive Order "Tackling the Climate Crisis at Home and Abroad" (Exec. Order No. 14008, 2021).

The BKIAM project brings together Alaska Native TK holders, scientists, educators, and fisheries managers to develop Indigenous Conceptual Models (ICMs) of the Arctic ecosystem using an interdisciplinary methodology, framework, and team. The ICMs will inform a suite of ecosystem modeling, climate change, and management projects at AFSC, including: Alaska Climate Integrated Modeling (ACLIM), Loss of Sea Ice (LOSI), PICES WG44, and the Bering Sea, Chukchi, and Arctic Integrated Ecosystem Assessments. The composition of the BKIAM team underscores a commitment to collaboration with ongoing modeling work and NPFMC research priorities. ICMs will interface with ecosystem models, contribute understanding of the changing Arctic ecosystem, support co-production approaches, and inform management decisions for a region undergoing rapid and unprecedented change.

This project has three objectives:

4. Promote interdisciplinary partnerships: BKAIM will aim to promote collaborations and partnerships among Indigenous Knowledge holders, scientists, and fisheries managers;
5. Develop Indigenous Conceptual Models: We will develop ICMs for the Arctic ecosystem based on Traditional Knowledge and rooted in interdisciplinary methods;
6. Document collaborative methods: We will document the collaborative methods used to bridge knowledge systems to inform fisheries management, outreach, and educational objectives, and promote successes as a model for other future efforts at AFSC.

A deeply collaborative process grounded in TK will improve management plans through robust inclusion of multiple ecosystem processes while creating better working relationships among Indigenous communities, researchers, the NPFMC and NMFS.

Communications To Support Co-Producing Science with Arctic Communities

Over the next five years to develop the Arctic Climate Regional Action Plan for 2025-2030, we would like to build relationships and work together with Indigenous communities to support Co-Production of Knowledge (CPK) research. The AFSC communications team will work to facilitate and strengthen enduring relationships among scientists and Arctic communities. CPK is a research framework that relies on trust and equity throughout the research process. As such, transparent, regular, and consistent communication is vital to ensure mutual and bi-directional dialogue to better inform our understanding of and response to marine ecosystem changes, largely due to Climate Change, that are dramatically affecting these communities' food security and way of life. Reliable and effective communication strategies can increase trust among participants and strengthen relationships, ultimately allowing for CPK research based on mutual priorities and grounded in Indigenous communities.

We intend to secure permission to attend Tribal Council meetings in the following communities in the fall of 2022 (working around hunting season): Utqiaġvik, Kaktovik, Kotzebue, Wainwright, Pt. Lay, and Point Hope. The goal of this meeting will be to start a dialogue. We will introduce ourselves, listen to community concerns and thoughts and discuss their interest in identifying ideas to co-produce research projects to help inform the next five-year Arctic RAP.

After that, we commit to meeting twice a year via conference call in 2023. In 2024, we will plan to meet in-person again with interested communities, in the communities, to flesh out these joint research priorities for inclusion in the 2025-2030 RAP report. During this timeframe, there may be joint project ideas identified that the community(ies) and the AFSCare interested in co-producing before the RAP is developed. To build broader awareness of the AFSCmission, other communications efforts are expected to coincide with this effort including:

1. Conduct radio interviews and local newspaper features to introduce the AFSCand highlight any projects that are jointly undertaken; and
2. Develop educational efforts targeting students, teachers and parents in the communities (e.g., regionally-focused interactive seminars for K-8 and internship opportunities for high school and college students).
3. Use NMFS communications platforms to highlight collaborative efforts (website, Facebook and other social media platforms regionally and nationally).

Members of the Alaska Fisheries Science Center's Communications and Social Science teams will assist the Arctic RAP chair with implementing this effort.

Predicting HABs and juvenile snow crab status using satellite-based measurements of ocean color

Rapid ocean warming and loss of sea ice are changing Arctic phytoplankton communities, with current models predicting reduced ice-edge blooms, increased open water production, decreased large lipid-rich diatoms and an increased frequency of harmful algal blooms (HABs). As ice melts earlier and open-water phytoplankton blooms occur in warmer water, pelagic productivity is expected to increase at the expense of benthic productivity. Recent ecosystem survey data indicate that phytoplankton cell-sizes are already decreasing and HAB cysts are increasing. During the 2017 to 2019 warming of the Chukchi Sea, the contribution of large diatoms to summer phytoplankton biomass decreased, and cysts of the harmful dinoflagellate *Alexandrium* spp. have now been found in the Chukchi and Beaufort Seas. NOAA scientists and their research collaborators are beginning to utilize satellite-based ocean color data to extrapolate our understanding of changes in phytoplankton over larger geographic scales, as well as hindcasting historical and forecasting future phytoplankton dynamics.

The specific objectives of this new project (2021-2024) include using satellite data to:

1. Develop a phytoplankton community size structure algorithm,
2. Advance a specific algorithm for the detection of small photosynthetic bacteria (*Synechococcus*),
3. Develop an algorithm for diatom abundance and
4. Explore to what extent satellite metrics can be combined with sea surface temperature (and other environmental variables), to provide predictions about HAB prevalence.

Predictive satellite algorithms for the prevalence of large lipid-rich diatoms would allow the development of valuable space-time maps of food quality at the base of the Arctic food web. In-situ samples of phytoplankton from Arctic ecosystem surveys (NBS and DBO cruises, 2021-2024), lipid analyses of phytoplankton samples, and satellite algorithms would allow us to develop essential fatty acid concentrations or ‘fat maps’ of the Arctic ocean surface and improve our understanding of food quality available to consumers over extended space-time scales. Monitoring and remote sensing efforts would be linked to new NOAA process studies (2021-2024) focused on the role of bottom temperatures and diatom flux in determining juvenile snow crab abundance and energetic status, including small mesh beam trawling efforts and controlled laboratory experiments on temperature- and food-dependent growth and lipid storage. We would synthesize findings from ecosystem monitoring, laboratory studies, new remote sensing algorithms and chemical biomarkers to mechanistically understand and forecast how environmental conditions will impact the energetic status of snow crabs (2024).

Renew Arctic Ecosystem Status Report

For fisheries managers to respond to rapid climate impacts within the Chukchi and Beaufort Seas, we recommend updating the Ecosystem Status Report (ESR) for the Arctic, as done in other LMEs in Alaska. This would provide the NPFMC with information on the status and trends of the ecosystems, LMRs, and resource-dependent communities in the Arctic. ESRs present a multi-dimensional examination of the ecosystem connecting ecological, economic, and human dimensions and support informed decision-making and sustainable resource management. The specific goal is therefore:

1. Update the Arctic ESR during 2022-2024

The Arctic ESR would prioritize collaboration with Alaska Indigenous communities and Traditional Knowledge holders in order to co-produce a report that reflects the best available science and can support managers in achieving stewardship goals. We recommend collaborating with Indigenous communities and Traditional Knowledge holders from the outset and the presentation of their knowledge alongside science to collectively present the "best science available" (National Standard 2). The Arctic ESR will coordinate with the Local Knowledge, Traditional Knowledge, and Subsistence Taskforce (noted in this RAP and the Bering Sea FEP) and adhere to their process and recommendations for relationship-building and consultation with Indigenous communities. The Arctic ESR would also benefit from close collaboration with the Bridging Knowledge to Inform Arctic Management (BKIAM) Project and the Communications To Support Co-Producing Science with Arctic Communities Project (both listed above in this RAP), both of which endeavor to cultivate enduring partnerships between communities, knowledge holders, scientists, and managers.

ESRs are distinct from other types of ecosystem assessments (such as the ICES/PICES IEA) in that ESRs are fully integrated within the regional fishery management council process. The ESRs are presented to the council and council affiliated bodies and committees alongside traditional fisheries information as a means to provide an ecosystem context for the council's annual decision making process. In contrast, IEAs and other synthesis efforts exist outside this process and may have different focal audiences. A key benefit of developing an Arctic ESR will be having a direct audience with the council to present ecosystem information on an annual basis, particularly given that AFSC is not likely to be doing stock assessments for individual species in the near future.

Cetacean sampling in the Chukchi Sea

Information on Alaska cetacean abundance, distribution, density, and trends in these parameters over time are required to understand how cetacean populations are responding to climate change and anthropogenic activities. At this time, a reliable abundance estimate is unavailable for approximately 50% of cetacean populations in Alaska, and an estimate of trend in abundance is available for approximately 15% of cetacean populations. The spatial distribution, seasonal timing, and condition of cetaceans have proven to be a sensitive indicator for climate-driven changes in sea ice and pelagic productivity (George et al. 2015).

We recommended a new program, the Arctic Marine Assessment Program for Protected Species (ArMAPPS). If implemented, ArMAPPS will include rotating assessment surveys and long-term tracking of cetacean populations in the Arctic (defined as north of the Aleutian Islands). We expect ArMAPPS will include both acoustics and survey components to address both changes in distribution and trends in abundance:

1. Maintain and improve passive acoustics: We recommend support of efforts to collect information on marine mammal distribution in the Chukchi Sea through passive acoustics; at this time, fieldwork is only partially supported and the manual labor required to process acoustics recordings is unfunded.
2. Develop and implement vessel and/or aerial survey: As a component of the ArMAPPS plan, we propose to assess distribution, density, stock structure, and movements of cetaceans in the Chukchi Sea via either a vessel-based or aerial survey; platform will be decided based on the final project goals and after discussions with key constituents such as the NMFS Alaska Region, BOEM, the Navy, and co-management partners.

Data will be analyzed in the context of passive acoustics and oceanographic data collected on moorings in the Chukchi. This project would benefit from concurrent fisheries and/or oceanographic surveys (not using the same vessel).

Overwinter survival of Arctic gadids

The biomass of pelagic fish on the Chukchi Shelf is dominated by juvenile gadids (~80%), cod species. Recent field studies indicate that changes in temperature and increased northward current flows have affected the distribution of boreal and Arctic gadids in the Chukchi Sea, and these trends are expected to continue given ongoing climate change. The late summer distribution of major juvenile cod species in 2019 showed walleye pollock expanding northward onto the central Chukchi Shelf while Arctic cod retreated to the most northern region of the shelf. However, we have little understanding of the overwintering physiology of juvenile gadids which impedes our ability to make informed predictions about their recruitment and establishment into adult gadid populations.

Although summer conditions on the Chukchi Sea are rapidly changing, overwintering conditions will still be prolonged, dark and cold. Both fish size and energy reserves will be critical in determining recruitment success of juveniles in Arctic waters. Small fish tend to be more vulnerable to overwintering starvation and predation risk. In the Arctic, extreme seasonality in food production requires that juvenile fish rapidly accumulate energy reserves during late summer, prior to entering an extending low food overwintering period. Indeed, Arctic cod contain 2 to 3 times more lipid reserves in late summer compared to boreal cod species and this high lipid state is generally viewed as an adaptation to overwintering in polar regions. Currently, we know little about how the energy storage of age-0 Arctic (Arctic cod and saffron cod) and boreal cod species (Pacific cod, walleye pollock) will be differentially impacted by warming summer temperatures and a concurrent reduction in zooplankton fat content.

Recent collections of juvenile Arctic cod in a warm year (2017) showed that they had 30% less fat storage than in previous cold years (2012 & 2013). Similarly, walleye pollock sampled on the Chukchi Shelf were similar in size to Arctic cod but contained 40% lower lipid than Arctic cod from the Northern Chukchi Shelf. Given the small size of these walleye pollock and their reduced lipid content, it is uncertain if they can survive Arctic winters and establish populations in the Chukchi Sea.

To address these questions, NOAA scientists will collaborate between AFSC laboratories to:

3. Predict impact of summing warming on juvenile condition: Conduct experiments to predict species-specific impact of warming summer temperatures and variable food quality on late summer juvenile size and condition
4. Predict impact of condition on overwinter survival: Conduct experiments to predict the species-specific impact of animal size and condition in fall as well as winter food availability and thermal conditions on their overwintering survival and energetics.

Expand Trophic and Spatial Models for Arctic Ecosystem

We recommend expanding AFSC modeling capabilities in the Arctic to improve understanding of key processes and features of the physical, biological, and human dimensions of Arctic ecosystems. An expanded modeling portfolio in the Arctic would support the development of climate-enhanced modeling necessary to produce projections for investigating tradeoffs among fisheries and conservation objectives while subject to ongoing climate change.

The Climate and Fisheries Initiative (CFI) currently intends (subject to funding) to develop a physical ocean and biogeochemical model for the Arctic (including the US Beaufort and Chukchi Seas). Such modeling of physical and lower trophic level conditions has been instrumental in other Alaska LMEs in providing forecasts of environmental conditions, such as the Bering Sea "cold pool", that are critical factors in the status and distribution of commercial, non-commercial, and protected LMRs. Additionally, biogeochemical ocean modeling has provided vital undergirding of climate-enhanced biological modeling used in MSE and projections of LMRs to identify management strategies robust to future climate scenarios.

We recommend that this CFI effort be complemented by AFSC efforts to maintain and update existing biological and human/socio-economic models, and initiate the development of new models (e.g., single-species, multi-species, food web, socio-economic, etc.) used to determine biological reference points and used for MSE and stock assessments, including:

1. Update Chukchi food web model: A food web model of the eastern Chukchi Sea, previously developed by AFSC scientists using the Ecopath with Ecosim (EwE) modeling framework, was last updated in 2016. We recommend updating the Chukchi Sea food web model with current information;
2. Develop Beaufort food web model: Developing a new EwE food web model of the US Beaufort Sea, between Utqiagvik and the Canadian maritime boundary. In combination with other existing EwE models of Alaska LMEs (eastern Bering Sea and Gulf of Alaska) and models currently under development (northern Bering Sea and eastern GOA);
3. Compare system-level optimum yield (OY) across all Alaska ecosystems: Using the continuum of food web models with a common modeling framework between SE Alaska and the Canadian Beaufort Sea to support comparative studies across a large latitudinal gradient, including an examination of system-level OY across ecosystems.
4. Spatio-temporal synthesis model for survey planning: Develop a new whole-of-ecosystem spatio-temporal synthesis model that fits to physical, lower-trophic, fish, and protected species survey data (both in situ and remote sensing), used to identify hotspots of density and/or productivity, detect trends in density/productivity over time (where feasible given available data), and subsequently used to optimize the design of future survey operations;

The trophic roles of ice seals in Chukchi and Beaufort seas

Recent extreme warm periods in the Alaskan Arctic have led to rapid declines in sea ice with potentially profound impacts on ice-dependent seal species. Bearded, ringed, spotted and ribbon seals compose a highly abundant guild of predators, whose trophic role in the seasonally ice-covered waters around Alaska is undoubtedly significant, yet their impact is poorly understood. The combined numbers of seals in winter and spring exceed one million individuals, likely consuming several million tons annually of a diverse suite of fish and invertebrate prey. To understand the full impacts of warming conditions on the Arctic marine ecosystems requires understanding of ice seal populations, trajectories, and responses to loss of sea ice.

Over the past decade, progress in monitoring ice seal abundance, distribution, seasonal movements, diets, and energetics has opened broad opportunities for collaboration to clarify the trophic roles of the seal species, quantify their impacts as predators, and determine their requirements for energy and prey. Data held by AFSC-MML, AFSC-ABL, the Alaska Department of Fish and Game (ADF&G), the North Slope Borough Department of Wildlife Management (NSB-DWM), University of California Santa Cruz (UCSC) and University of British Columbia (UBC) will support collaborative syntheses that, for the first time, will afford meaningful inclusion of phocid seals in Ecosystem Status Reports, integrated ecosystem models, and protected species assessments for Alaska LMEs. The work will proceed in phases over fiscal years 2022-2024.

This project will specifically deliver:

1. Estimates of seasonal ice-seal prey requirements: estimate bearded, ringed, spotted, and ribbon seals' seasonal and regional requirements for their dominant prey species by integrating results from spring surveys of seal abundance and distribution, satellite-tracking studies of seasonal seal movements, ice seal prey composition studies, energy assays of prey, and energetic models.
2. Estimates of seasonal and spatially explicit ice-seal consumption: it will then expand these seasonal prey requirements based on predicted seasonal distribution and abundance for ice seals, to identify total consumption by ice seals of fish and demersal resources in the Chukchi and Beaufort Seas. This estimate of consumption is then necessary to understand trophic processes and how these are likely to change as climate change affects the spatial distribution and seasonal timing of ice-seal populations.

Focused involvement regarding demersal communities within the Distributed Biological Observatory

The DBO is a cross-agency tool for monitoring changes across the Bering Sea, Chukchi and Beaufort, and includes deployment of oceanographic moorings, net collections of zooplankton and ichthyoplankton, and passive acoustics for marine mammals. The DBO therefore represents a cost-effective platform to collect information relevant to changes in demersal fish communities, which may in the future be colonized by species that are fished in the Bering Sea.

We recommend the following extensions during the 2022-2024 planning period:

1. Add beam trawls: We recommend detecting key taxa such as Arctic cod, saffron cod, Pacific cod, pollock and snow crab using a small-mesh beam trawl, which could operate from the DBO survey vessel already supported in late summer.
2. Extend exploratory large-mesh trawling: As extension of the existing northern Bering Sea survey, we recommend at least one year (and ideally several years) that the charter be extended to the DBO3 line in the southern Chukchi to detect larger, adult individuals of the above key taxa. This could involve as few as two stations per day, and perhaps 3 days total.
3. Add benthic respirometer: Benthic respiration is a direct measure of oxidative metabolism of benthic carbon for the benthic community, and therefore measures biological use of benthic resources. We recommend adding a measurement of benthic respiration to all DBO moorings. This measurement would complement existing infaunal sampling, but with emphasis on the role of benthic organisms in benthic energy and nutrient flow.
4. Add environmental DNA: eDNA is a technology with growing application to detect community-wide and species-specific occurrence within waters that are sampled and subsequently analyzed for the presence of DNA fragments. We recommend developing eDNA assays for key species (e.g., Pacific cod and walleye pollock) to detect whether these species are occurring near the DBO3 line or further north, where such a detection could trigger large-mesh trawling as discussed in #2 above.

Collectively, these activities would allow AFSC to rapidly detect interannual variation in the northward extent of fish populations that also inhabit the Bering Sea, to anticipate future shifts due to climate change. In particular, eDNA would allow for rapid and cost-effective detection of range extension, while beam and large-mesh trawls are both needed to measure density and collect biological information (size/age/condition) from both juvenile and large bodied fish species. Finally, benthic respirometry would efficiently measure changes in benthic production at these fixed monitoring stations.

Local Knowledge, Traditional Knowledge, and Subsistence Taskforce for Arctic Region

In 2019, the NPFMC authorized the implementation of the Local Knowledge Traditional Knowledge and Subsistence (LKTKS) taskforce under the Bering Sea Fishery Ecosystem Plan (BS FEP). The plan formalized an ecosystem-based management (EBM) approach to Bering Sea fisheries, recognizing the critical importance of local knowledge and Traditional Knowledge in better understanding ecosystem processes. The BS FEP Taskforce is a nominated body composed of Indigenous and non-Indigenous issue experts with diversity in individuals' community of practice, geographic location, and academic training. The BS FEP Taskforce's main purpose is to create a protocol for how to access and use LK, TK, and subsistence information in existing management processes and institutional frameworks.

Drawing on the BS LKTKS taskforce as a model, we propose the AFSC works with the NPFMC, Indigenous, and non-idigenous experts to create an Arctic Taskforce to explore ways to bridge multiple knowledge systems, and inform ecosystem-based management to resilience pathways within the region. In particular, this LKTKS Task Force is necessary to encourage formal two-way communication about climate impacts for frontline communities. We propose to:

1. Convene Arctic LTKTS Task force: Identify members and convene this new Arctic LKTKS Task force by 2024, in preparation for updating the next round of the Arctic RAP.

Bottom trawl and acoustic-trawl survey to detect northward distribution shifts

The ecosystem of the Alaska Arctic is changing rapidly as the ecosystem warms. There have been striking shifts in fish community structure in recent years. For example, walleye pollock and Pacific cod have become abundant in the Northern Bering Sea (Stevenson and Lauth 2019), and age-0 walleye pollock have comprised a much larger fraction of the age-0 gadids that dominate the pelagic fish community over much of the Chukchi shelf in recent years (Levine et al. 2021). Although a commercial fishery for pollock has opened in Russian waters, it remains unclear if/when boreal species will colonize US areas of the Chukchi Sea. Despite these major changes in ecosystem structure, there is no consistent monitoring of larger fishes in the Alaska Arctic. Beam trawls alone are insufficient for this type of sampling, as they do not adequately sample the highly abundant midwater fish community and many of the larger species that are important in the subsistence harvests of the native communities (e.g., large gadids, sculpins, eelpouts, snailfishes) may become increasingly important components of the changing Arctic marine ecosystem.

We propose the following strategy to sampling densities of large-bodied demersal fishes, decapod crabs, and midwater fishes in the Chukchi Sea:

1. Develop survey design: Develop a specific spatial, seasonal, and gear-specific sampling design for sampling using large-mesh bottom trawl and acoustic-midwater trawl gears (De Robertis et al. 2017). This could use habitat models fitted to prior bottom and midwater sampling to optimize specific station placement and the spatial extent under alternative funding scenarios, based on similar successful efforts in the Gulf of Alaska (Oyafuso et al. 2021);
2. Conduct short gear trial: If needed, conduct a short (1-2 day) gear trial to test our ability to fish small-mesh midwater trawls and large-mesh bottom trawls efficiently on a single vessel, including testing rigging modifications to allow both trawls to be deployed without switching trawl doors between gears;
3. Implementation: Implement sampling following the planned design during a single year, ideally during 2022-2024.

Sampling will focus on large-bodied fishes and crabs that are not well sampled with methods used on the DBO cruises. The expedition will be designed to update prior sampling using large-mesh bottom trawls in 2012, and acoustic-trawl gear in 2012/2013 and 2017/2019. Updated information about demersal and midwater abundance for large-bodied fishes is necessary to understand the extent to which climate change is shifting species that are fished within the Bering Sea northwards into the Chukchi Sea, and could provide specimens to inform other activities in the plan (e.g., “Overwinter survival of Arctic gadids”)

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