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Contents

Executive Summary

Changing climate and oceans are affecting the Nation's valuable living marine resources and the many people, businesses, and communities that depend on them. Warming oceans, loss of sea ice, rising seas, extreme events, and acidification are impacting the distribution and abundance of species, and the structure of marine and coastal ecosystems in many regions. These impacts are expected to increase and there is much at risk.

To prepare for and respond to climate impacts on marine and coastal resources, the 2015 NOAA Fisheries Climate Science Strategy (NCSS) identified seven key objectives to increase the production, delivery, and use of climate-related information needed to fulfill the agency's mandates (e.g., fisheries management, protected resources conservation) in a changing climate. Beginning in 2016, the National Marine Fisheries Service developed Regional Action Plans (RAPs) to implement the NCSS in each region based on regional needs and capabilities. A summary of accomplishments from the initial Eastern Bering Sea Regional Action Plan (EBS RAP) can be found in the NCSS 5-year Progress Report.

To effectively manage the Nation's living marine resources (LMRs) under changing climate and ocean conditions, this updated EBS-RAP presents current and proposed activities to continue to implement the NCSS in the region through 2024. This updated EBS RAP builds on the initial EBS-RAP and describes planned and ongoing research being conducted by the Alaska Fisheries Science Center (AFSC) and partners. It also identifies areas of needed research to increase the delivery of fishery and climate decision support products needed by the North Pacific Fishery Management Council (NPFMC), and it will enable managers, businesses, and fishing communities to better respond to climate variability and change. These activities support NOAA's effort to build a climate-ready nation.

The EBS RAP includes ongoing research to implement our federal mandate as outlined in the Alaska Fisheries Science Center's Strategic Science Plan. It also includes recommendations for additional research that we believe is needed to help us respond to climate change. Much of the ongoing work outlined in this document is occurring in close collaboration with partners. The proposed actions will likely require additional funding and support to be completed during this timeframe, and will also involve ongoing and strengthened collaborations with many Tribal, governmental, and nongovernmental bodies including the State of Alaska.

This EBS RAP includes over 50 climate-relevant science activities to address priority needs in five key focus areas: Monitoring, Process Studies, Management-Oriented Synthesis, Marine Mammals, and Socioeconomics. It also includes metrics to help measure and track progress. Implementation of this plan is contingent upon NMFS prioritization and available resources.

The following is a summary of key actions and the NCSS objectives they address.

Maintain Mechanistic Research, Infrastructure, and Track Change (NCSS Objectives 5-7)

- Maintain core fisheries and cetacean surveys in the eastern Bering Sea. Maintain and improve model-based survey biomass estimates. Evaluate implications of current and alternative survey sampling designs.
- Maintain and improve the fishery monitoring and assessment program and evaluate implications of adoption of electronic monitoring on stock assessments.
- Deploy moorings and invest in new technologies to enhance data collection from existing survey platforms.
- Assess fishery-dependent community responses to climate-induced ecosystem change. Produce Alaska Community Engagement and Participation Overview (ACEPO) reports and Economic Stock Assessment and Fisheries Evaluation (Econ SAFE) reports.
- Conduct laboratory and field research on the mechanistic effects of multiple climate factors (e.g., temperature, ocean acidification, dissolved oxygen) on living marine resources with the goal of informing process-based models for single species, multi-species, and the ecosystem.
- Conduct ecosystem surveys of the eastern and northern Bering Sea for assessing physics, phytoplankton, zooplankton, and larval juvenile fish abundance and condition.

Inform Climate, Ecosystem and Fisheries Decision Support Systems (NCSS Objectives 1-4)

- Maintain and improve the multimodel suite used to assess the implications of climate change on fish and shellfish through the delivery and uptake of climate nowcasts, forecasts and projections.
- Use the results of ecosystem-linked assessments and climate projections to assess impacts on fisheries and fishery-dependent communities.
- Continue production of annual stock assessments, ecosystem status reports (ESRs), ecosystem and socioeconomic profiles (ESPs), risk tables, and climate change task force (CCTF) products that include climate-relevant information.
- Improve use of spatial information derived from observations and species distribution models in management decisions.
- Complete Management Strategy Evaluation and Scenario Planning through completion of ACLIM - Phase 2.
- Work with federal and academic partners to develop and improve regional hindcasts, forecasts, and projections of ocean and estuarine/river physics, sea ice, and biogeochemistry.
- Increase social and economic scientist involvement in climate change research.
- Transition at least one assessment from the semi-quantitative statistical analysis of ecosystem indicators in ESPs to an evaluation of an alternative for an operational ecosystem-linked stock assessment model. Explore using Fisheries Integrated Modeling System software for at least one assessment.

Introduction

Alaska is on the front lines of climate change (https://www.ipcc.ch/report/ar6/wg1/). Large changes in ocean conditions are projected in the Bering Sea (Hermann et al. 2021, Cheng et al. 2021). Such changes may have cascading impacts on regional food webs (Reum et al. 2020). The eastern Bering Sea (EBS) supports some of the most valuable commercial fisheries in the world and subsistence harvests are a critical resource for coastal communities. High numbers of seabirds and marine mammals also are found in the region. Climate-related changes in ocean and coastal ecosystems are impacting the plankton, fish, seabirds, and marine mammals of the southeastern Bering Sea, as well as the people, businesses, and human communities that depend on them (Meridith et al. in press). Actionable information on when and how climate change will continue to impact Alaska is needed.

Scientists and managers at NOAA's Pacific Marine Environmental Laboratory (PMEL), Alaska Fisheries Science Center (AFSC), and Alaska Regional Office (AKRO) engage in research and management to fulfill the responsible stewardship of the Nation's Living Marine Resources (LMR) and their habitats (http://www.nmfs.noaa.gov/aboutus/our_mission.html). The enabling legislation for the National Marine Fisheries Service (NMFS) mission is found in the Magnuson-Stevens Fishery Conservation and Management Act (MSA), Marine Mammal Protection Act (MMPA), National Environmental Policy Act (NEPA), Endangered Species Act (ESA), and other governing legislation. To continue to fulfill this mission in the face of climate change, the AFSC seeks to acquire information and develop science-based strategies for sustaining fisheries, healthy ecosystems, protected species, and coastal communities in a changing climate.

This Eastern Bering Sea Regional Action Plan (hereafter EBS-RAP 2.0) builds on the previous success of the initial EBS RAP (Sigler et al. 2016, Peterson et al. 2021) and conforms to a nationally consistent blueprint, the NOAA Fisheries Climate Science Strategy (NCSS). The NCSS guides efforts by the NMFS and its partners to address information needs and is organized into seven science objectives that address the Nation's challenges in sustaining and managing LMRs in the face of a changing climate. The EBS RAP 2.0 identifies strengths, weaknesses, priorities, and actions to implement the NCSS in the region through 2024. Successful implementation of the EBS RAP 2.0 will require enhanced collaboration with our partners. These activities support NOAA's effort to build a climate-ready nation.

Reducing the impacts of changing climate and ocean conditions on living marine resources and resource-dependent communities is contingent upon both mitigation and adaptation. Mitigation measures to reduce current and future greenhouse gas emissions or remove carbon dioxide from the atmosphere are key factors in determining which future climate scenario that we are headed towards and the degree and types of adaptation needed to increase the resilience of fisheries and communities.

NOAA is working to reduce green-house gas emissions from its facilities and ships (DOC 2021 Climate Action Plan) as well as acting to increase resiliency and adapt to current and anticipated impacts of changing climate and ocean conditions on living marine resources. This EBS-RAP discusses actions to address and adapt to current and anticipated impacts of changing climate and ocean conditions on living marine resources. Such efforts will increase the resilience of the Nation's valuable living marine resources and the people, businesses, and communities that depend on them.

Reason/rationale for updating Regional Action Plan

The recent completion of the Intergovernmental Panel on Climate Change (IPCC) Special Report on Oceans and Cryosphere in a Changing Climate (IPCC 2019; https://www.unep.org/resources/report/ipcc-special-report-ocean-and-cryosphere-changing-climate) underscores the urgency for improved climate, ecosystem and fisheries decision support systems to effectively respond to rapidly changing ocean conditions. This need is amplified in high-latitude systems where the effects of changing climate conditions are being experienced more dramatically. Evidence of this rapidly changing climate is seen in the increased occurrence of marine heat waves in the region with profound impacts on the production and distribution of managed resources (Hunt and Hirawake 2020).

The AKRO, which oversees the science-based stewardship of living marine resources and their habitat in the Bering Sea, relies on climate science information to support its stewardship mandate, including for work by its Sustainable Fisheries, Protected Resources, and Habitat Conservation Divisions (SF, PRD, and HCD, respectively). In the HCD, climate research products from activities in the EBS 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 EBS 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 Bering Sea. Sustainable Fisheries 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. Sustainable Fisheries continues to support the North Pacific Fishery Management Council's Bering Sea (BS) Fishery Ecosystem Plan (FEP), including participation on the BS FEP Climate Change Task Force, support for the AFSC's efforts to build a comprehensive Bering Sea Integrated Ecosystem Assessment, and to be responsive to specific data and management needs related to climate-forcing events. Protected Resources uses climate data from the EBS to inform decisions for ESA-listings, critical habitat designations and Section 7 consultations. Protected Resources takes climate data into consideration when evaluating stock status, status of a species, and expected impacts upon

protected species. The AKRO's climate information needs in the Bering Sea span a range of stewardship objectives and are supported by the research projects described in this RAP.

During the first implementation of the RAPs, it was envisioned that research on climate change and fisheries would evolve over time and thus periodic updates of the RAPs would be required. Upon completion of the NCSS 5-year review, NMFS leadership concluded that an update of the RAPs was both timely and necessary. This document provides an update of the current and planned research projects and an evaluation of the remaining key scientific gaps (Appendix).

The broad goal of the EBS RAP 2.0 is to provide NOAA leadership, our key stakeholders, and resource managers with a clearer understanding of current LMR-relevant climate-related projects, activities, and research that are occurring across NOAA and in conjunction with our national and international partners. Climate variability and change have been central areas of interdisciplinary research at AFSC for over 25 years [see the Bering-FOCI, Southeast Bering Sea Carrying Capacity regional program (SEBSCC, 1996-2004), the Bering Ecosystem Study - Bering Sea Integrated Ecosystem Research Program (BEST-BSIERP, Bering Sea Project 2007 - 2012), and the Alaska Climate Integrated Modeling project (ACLIM, https://www.fisheries.noaa.gov/alaska/ecosystems/alaska-climate-integrated-modeling-project, 2015 - present)]. The ACLIM Project has built on earlier work and has focused on making Bering Sea fisheries management climate-ready. The ACLIM Project is an interdisciplinary team of researchers convened to explore how climate change is likely to impact marine ecosystems and the fisheries that depend on them (Hollowed et al. 2020). The project engages managers and stakeholders to define scenarios that help to make the fishery management system more robust in the face of environmental, economic, and management uncertainty.

While ACLIM has played a central role in AFSC's climate research efforts, a diversity of other work is ongoing or planned over the next 3 years. Some projects relate to operationalizing climate-ready fisheries management while other work is focused on other NOAA mandates such as the ESA. When taken together, this set of climate research activities contributes to all seven of the NCSS objectives. The metrics associated with each activity allow for an accounting of the progress toward ecosystem-based fishery management (EBFM) and sets a strong baseline for the AFSC's EBS climate research portfolio.

Despite the significant number of activities that are currently occurring, many gaps remain in conducting the research and monitoring needed to support the Nation's largest fisheries and one of its most dynamic ecosystems. The environment is changing extremely rapidly and is challenging the current resource management system. In a short period of time, there have been major changes in the ecosystem, including recurrent marine heat waves, the loss of sea ice, and dramatic distribution shifts of several commercially important groundfish stocks (e.g., pollock, Pacific cod, yellowfin sole) into the northern Bering Sea (NBS) (Spies et al. 2018, Lauth et al.

2019). As part of the NCSS, EBS RAP 2.0 updates NOAA's efforts currently underway to increase the production, delivery, and use of the climate-related information required to fulfill the agency's mission. The goal of the EBS RAP is to build a portfolio of integrated, "climate-ready" actions to support NMFS' decisions under a changing climate.

Existing Climate Change Research Portfolio

The NCSS 5-year synthesis revealed that although NOAA currently maintains a research portfolio in the EBS that is consistent with governing legislation, additional research is needed to prepare for and respond to changing climate. The existing research portfolio addresses the seven objectives of the NOAA Fisheries Climate Science Strategy (Link et al. 2015, listed below); however, key gaps exist.

Objective 1. Identify appropriate, climate-informed reference points for managing living marine resources (LMRs).

Objective 2. Identify robust strategies for managing LMRs under changing climate conditions.

Objective 3. Design adaptive decision processes that can incorporate and respond to changing climate conditions.

Objective 4. Identify future states of marine, coastal, and freshwater ecosystems, LMRs, and LMR-dependent human communities in a changing climate.

Objective 5. Identify the mechanisms of climate impacts on ecosystems, LMRs, and LMR-dependent human communities.

Objective 6. Track trends in ecosystems, LMRs, and LMR-dependent human communities and provide early warning of change.

Objective 7. Build and maintain the science infrastructure needed to fulfill NMFS mandates under changing climate conditions.

A brief overview of the existing research portfolio (Fig. 1) reveals that NOAA maintains a suite of scientific observations which track current and future stock status relative to key biological reference points and other national standards; although important gaps exist. Evaluating the trends (NCSS objective 6) and identifying the mechanisms of climate impacts (NCSS objective 5) to develop climate-informed reference points (NCSS objective 1) can be problematic due to the mismatch in the spatial and temporal resolution of biological, human dimensions, and physical data sets. The older survey projects began well before concerns about the impacts of climate change, and hence physical and biological surveys were not originally integrated. Yet, as resources permit, existing projects have been modified and new projects developed to integrate physical and biological observations. For example, the AFSC and PMEL have historically aligned independent oceanographic survey efforts with larval and juvenile fish field surveys to provide the improved synoptic data sets to develop a mechanistic understanding of climate

impacts on early life history (NCSS objective 5)**.** In the last decade, the AFSC and PMEL have partnered to identify opportunities for expanding physical and biogeochemical sampling for sub-adult and adult groundfish surveys, particularly on EBS and GOA acoustic-trawl surveys where sampling has been extended to include euphausiid (a key prey species) backscatter (Simonsen et al. 2016). The Bering Seasons and ACLIM 2.0 projects use this mechanistic understanding to forecast seasonal changes in ocean conditions and to project the future distribution, abundance, and status of LMR under a changing climate (NCSS objective 4). Integrated projections from ACLIM 2.0 are used to assess the performance of current and alternative harvest strategies and adaptation pathways (NCSS objectives 2 and 3), and to identify climate-informed biological reference points (NCSS objective 1). In collaboration with the NPFMC's Climate Change Task Force (CCTF), Fisheries Ecosystem Plan Team (FEP), and Scientific and Statistical Committee, results from integrated research efforts of PMEL and AFSC are communicated to the NPFMC. As our scientific infrastructure (NCSS objective 7) and institutional experience increase and the predictive skill of our models improve, the AFSC will provide climate-informed reference points to the adaptive management processes (NCSS objective 3) of the Council and AKRO.

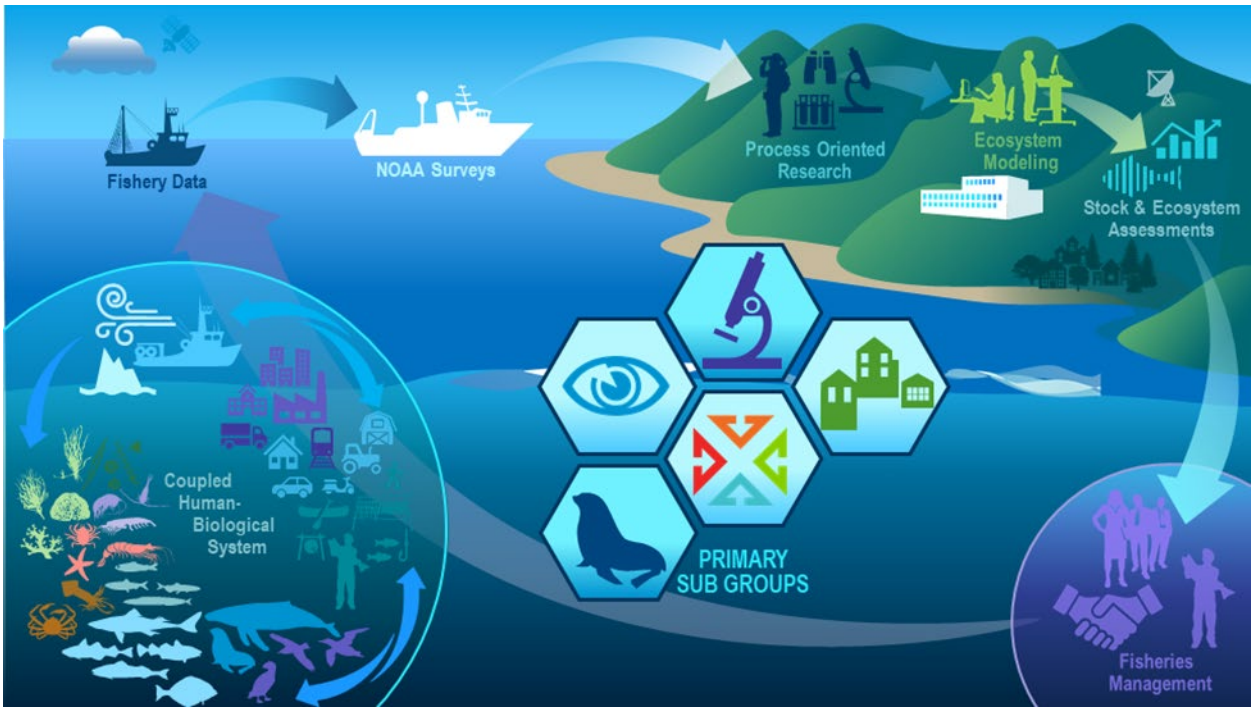

Figure 1. -- Schematic representation of the relationship between the focus areas (primary subgroups, see Table 1) and the Alaska Fisheries Science Center's integrated climate change research portfolio.

In the next 3 years, NOAA plans to support 51 climate research activities in the EBS (Table 1; Appendix). These projects were organized into five focus areas: Monitoring, Process Research, Management-Oriented Synthesis, Marine Mammals, and Socioeconomics. These focus areas roughly map into the NCSS objectives as shown in the schematic below (Fig. 2). The five focus

areas were included in EBS RAP 2.0 to align the NCSS objectives with internal strategic planning efforts within the AFSC and AKRO. Sub-leads within the writing team were designated for each of these focus areas to seek balanced representation of research needs across disciplines in the report.

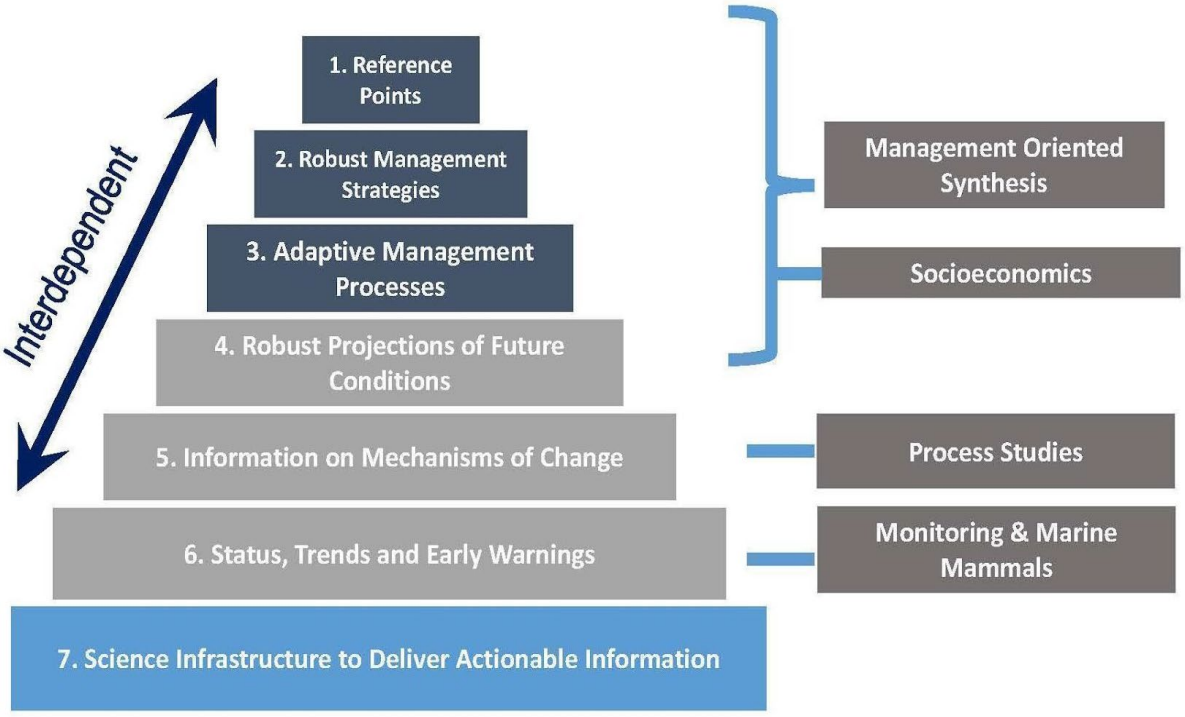

Figure 2. -- Schematic representation of the relationship between the seven National Marine Fisheries Service Climate Science Strategy objectives and the five focus areas identified in this Regional Action Plan.

Table 1. -- Summary of continuing climate change projects, projects started after 2013 and projects intended to fill key gaps in the Eastern Bering Sea Regional Action Plan climate change research portfolio.

Continuing Projects	Objective	Sub Group
Stock Assessment Enterprise	1, 2, 6, 7	
Multispecies technical interaction model	2	
Management strategy evaluations (MSEs)	2	
Alaska Integrated Ecosystem Assessments and Ecosystem Status Reports	6	
Alaska Integrated Ecosystem Assessments and Ecosystem Status Reports	6	
Fisheries Monitoring and Assessment	6, 7	
Fish and Crab Surveys	6, 7	
Age and Growth Monitoring	6, 7	
Marine Mammal Assessments	6, 7	
Seabird Bycatch and Encounters	6, 7	
Standard Shipboard Oceanographic Collections for Ecosystem Monitoring	6	
Standard Ichthyoplankton and Juvenile Fish Monitoring	6	
Oceanographic Moorings	6	
Derived products from ecosystem monitoring	5, 6	
Groundfish Stock Structure and Salmon Stock Identification	6	
Recruitment Processes Alliance (RPA)	5	
Ocean Acidification Research	5	
HABs Research	4	
Satellite tagging of northern fur seals	5, 6	
Support for rapid response indicators of ecosystem status	6	
Identify bio-geochemical thresholds and mechanisms driving ecosystem reorganization	5	
Northern fur seal research	2, 5, 6	
Assess economic and social impacts of climate change	3	
Modeling fisher behavior in response to changing climate, markets and management	3	
Identify human community dependence on LMRs and effects of climate change	3	
Regional Economic Impacts of Climate Change	3	
Arctic Council, AMAP, impacts on coastal communities	3	
Integrated economic impact assessments of Ocean Acidification	3, 5	
Community and economic surveys	3	

Post 2016 Projects	Objective	Sub Group
Inshore and coastal assessments	6	
eDNA (northward shifts)	7	
Shifting Spatial Distributions	6	
Biogeochemical process monitoring	4	
Ecosystem and Socioeconomic Profiles (ESPs)	5	
Risk Tables	1, 5, 6	
Species Distribution Models for Identifying Essential Fish Habitat	5	
Transition from ROMS to MOM6	4	
Bering Seasons program-phase 2	4	
The Alaska Climate Integrated Modeling Project Phase 2	1–4	
Northern fur seal foraging model in ACLIM Phase 2	3. 5	
Fisheries Integrated Modeling System	1, 2	
Council Bering SEa FEP Local Knowledge Traditional Knowledge and Subsistence Taskforce	2, 3, 6	
Climate Change and Crab Working Group	1, 5	
Incentivize collaboration (NMFS, DFO and PICES	2, 4, 5	
The PICES/ICES Working Group on Impacts of Warming on Growth Rates and Fisheries Yields	1, 5	
Sustainability of Marine Ecosystems through global knowledge networks	4, 5	
Modeling the management and fishery response to changing fishing abundance with the ACLIM ATTACH Model	3	
Developing socioeconomic scenarios to evaluate possible future management and harvest scenarios	3	
Identifying fishing effort by modeling Vessel Monitoring System (VMS) and Automatic Information System (AIS) data	5	
Annual Community Engagement and Participation Overview (ACEPO)	5	
Communication foundation for co-producing science with Bering Sea communities	3	

Gap Projects	Objective	Sub Group
Discretionary Funds for Rapid/ Emergency	6, 7	
Supplemental Support for Southeastern Bering Sea Ecosystem Assessment and Monitoring Surveys	6, 7	
Supplemental Support for Northern Bering Sea Ecosystem Assessment and Monitoring Surveys	6, 7	
Forage Fish Population Dynamics	7	
Expand Marine Mammal Assessments	3, 6, 7	
Fully support NOAA oceanographic moorings	6, 7	
Expanded bio-physical data collections on NOAA moorings	6, 7	
Expanded bio-physical data collections on NOAA uncrewed surface vehicles	5–7	
Laboratory infrastructure - environmental tolerances, food habits and bioenergetics	5–7	
Information trade-offs with current and alternative sample size and data collection methods	6, 7	
Strengthen partnerships with Russian Federation to share data on transbound-ary stocks	6, 7	
Communication, Cooperation and Infrastructure to Increase Efficiency and Comfortability of Monitoring Data	7	
Euphausiid population dynamics	5–7	
Nearshore ecosystems and juvenile fish population dynamics	5	
Climate Fisheries Initiative funding for Fisheries and Climate Decision Support Systems	1–5	
AFSC Climate Research and Activity Facilitator	7	
Improve communication of risks of climate change to fishing dependent communities	3	
Bridging knowledge to inform Bering Sea Management (BKIBS)	3	
Invest in training, education, and infrastructure though implementation of CFI FACSS	1-7	
Arctic marine assessment program for Protected Species (ArMAPPS)	6, 7	
Modernize Alaska marine mammal assessment surveys	5, 6	
Expand research to understand how climate change will impact fishery-dependent human communities and evaluate socioeconomic scope for adaptation	3	
Adapting to Life Without Ice: Food security, subsistence, and nutrition in the Bering Strait	3	
Non-market values of the Bering Sea ecosystem	3	
Ecosystem service valuation (SPURF)	3	

NCSS OBJECTIVES

1. Climate-Informed Reference Points
2. Robust Management Strategies
3. Adaptive Management Processes
4. Project Future Conditions
5. Understand Mechanisms of Change
6. Track Change and Provide Early Warnings
7. Build and Maintain Adequate Science Infrastructure

PRIMARY AFSC SUB GROUP

- Monitoring
- Socio-economics
- Process Research
- Marine Mammals
- Management - Oriented Synthesis

Table 2. -- Summary of the existing climate-related research portfolio for the eastern Bering Sea (see Appendix for detailed project descriptions).

Focus areas	Total projects	Continuing projects	Post 2016 projects
Monitoring	12	10	2
Process Studies	8	6	2
Management-Oriented Synthesis	18	4	14
Marine Mammals	1*	1	
Socioeconomics	12	7	5
Total	51	28	23

*Marine mammal abundance surveys (Appendix project M4) and vital rate data collection are included in Monitoring and Process Studies, and marine mammal foraging model development is included in Management-Oriented Synthesis. Targeted funding for continuing climate related studies for northern fur seals is temporary.

Of these 51 projects, 28 projects are continuing and 23 projects were initiated in response to EBS RAP 1.0 (https://repository.library.noaa.gov/view/noaa/12964) or other initiatives (Table 2). These 51 projects are the major research projects that rely on federal funding or enlist federally funded researchers but do not represent the full landscape of research occurring in the EBS. Numerous non-governmental, academic, commercial, State, Tribal, private industry representatives and international research institutions also conduct research in the EBS. These external research bodies provide valuable information that expands the scope of climate research in the region. The projects listed in Table 1 represent NOAA's contribution to scientific research in the eastern Bering Sea relevant to the NCSS objectives.

When viewed across focus areas, the largest number of research projects fell into the Management-Oriented Synthesis category. This can be traced to numerous factors including the 1) the long history of large integrated research which served to form trust and sound working relationships between scientists; 2) the interest of fishery-dependent communities in fisheries science and climate impacts; and 3) the acceptance of ecosystem-based management approaches by the NPFMC, and the foundational training in EBM provided by our partners in academia. The NCSS provided a strong catalyst for advancing this integrated research.

Highlighted Opportunities for Tactical Advice

NMFS encourages the formation of conduits for including ecosystem advice in tactical decision making. Among the 23 new research projects, 5 are particularly relevant to the successful delivery of climate-informed tactical advice. These projects developed in response to the updated

Stock Assessment Improvement Plan (SAIP), the Integrated Ecosystem Assessment (IEA) program and the NCSS.

1. **Ecosystem and Socioeconomic Profiles (ESPs).** Ecosystem and Socioeconomic Profiles are a framework for compiling, evaluating, vetting and assessing the predictive skill of species-specific ecosystem and socioeconomic linkages (Shotwell et al. accepted). Ecosystem and Socioeconomic Profiles serve as an on-ramp to the development of ecosystem-linked stock assessments of fishes and crabs.
2. **Risk Tables.** To facilitate consideration of relevant information on factors influencing stock status from both ecosystem status reports (ESRs) and ESPs that is not already addressed within the stock assessment model, scientists at the AFSC developed risk tables (Dorn and Zador 2020). The risk tables are included in stock assessment and fishery evaluation (SAFE) reports and the information contained in these documents is considered by the NPFMC scientific review teams (Plan Teams and SSC) prior to setting harvest advice (i.e., Acceptable Biological Catch, Overfishing Levels, and the Annual Catch Limit).
3. **Fisheries Ecosystem Plan (FEP) Task Force Teams.** Increased awareness and the Council's growing appetite for climate change advice, led to the adoption of the Bering Sea Fisheries Ecosystem Plan (BSFEP). The FEP includes the Climate Change Task Force (CCTF) and the Local Knowledge/Traditional Knowledge/Subsistence Task Force (LKTKSTF). These task force teams serve as a conduit for the dissemination of climate change-related research products to managers and the public.
4. **Human Integrated Ecosystem-Based Fishery Management (HI-EBFM).** NMFS has developed a Socioeconomic Strategic Plan that emphasizes climate change and interdisciplinary research as a general priority for the agency. AFSC economists and social scientists will prioritize the integration of their work with the diverse climate-related activities.
5. **Fisheries Integrated Modeling System (FIMS).** The recent effort by NMFS to modernize and integrate the diverse suite of stock assessment models into a community-based Fisheries Integrated Modeling System (FIMS) will help to facilitate the exploration of ecosystem-linked assessments for fishes and crabs. Efforts are currently underway to develop the design specifications for FIMS with the goal of having an operational modeling system available by 2025. FIMS is expected to accelerate the testing of candidate ecosystem linkages that are advanced through the ESPs for Bering Sea stock assessments. This may contribute to the delivery of climate-informed reference points (NCSS Objective 1).

Emerging Research Opportunities

Four emerging opportunities are expected to be implemented in the near future. These four projects will improve the AFSC's ability to support and deliver the science to make climate-informed decisions for management of commercial fisheries in Alaska.

NOAA's Climate, Ecosystems, and Fisheries Initiative (CEFI): In response to clear evidence of the profound role of climate on marine resources, fisheries, communities and economies in the United States, NOAA developed the CEFI to meet the high and growing demand for climate-informed advice. The CEFI enlists all branches of NOAA Line Offices to build an end-to-end operational Decision Support System that will fill critical gaps in the information needed for climate-informed decision making, including robust forecasts and projections of future ecosystem conditions and evaluation of best management options for changing oceans. The proposed CEFI System is composed of five components including Decision Support Teams at NMFS' science centers to develop the information and advice decision makers need to help reduce impacts and increase resilience and adaptation over near and longer timeframes. The CEFI is designed to provide the critical regional infrastructure needed for climate-informed decision making for marine resources and resource-dependent communities. The CEFI will build on regional pilot projects like ACLIM and Bering Seasons. If implemented, the CEFI will provide core capability and a variety of regular products and services to advance the NCSS and climate-informed decision making such as follows:

- Critically needed high spatial and temporal resolution ocean model products (including pH, nutrients, phytoplankton, and zooplankton) at multiple time scales (sub-seasonal, seasonal, decadal and multi-decadal).
- Research and development to ensure the fish or fishery specific products derived from these models provide the best available scientific information on evolving ocean conditions.
- The interdisciplinary analysts and information support specialists (scientists at Geophysical Fluid Dynamics Laboratory (GFDL), PMEL, AFSC and NOS) necessary to implement and sustain fisheries and climate change impact assessments, fishery-dependent adaptation response assessments, and scientific decision support products for the NPFMC.

It is anticipated that the CEFI will build on the advances derived from ACLIM Phase 2 and the Bering Season Phase 2 projects to launch a new era of climate change research within NMFS providing major advancements in **objectives 1-4** of the NCSS. The availability of accessible, reliable and verifiable model-derived physical and biogeochemical ocean products will allow analysts to design and test ecosystem linkages at the appropriate temporal and spatial scales for managed fish, crab, and protected species.

NMFS survey infrastructure: In recognition of the growing need for ongoing and expanded ecosystem linked sampling and analysis, NMFS submitted a request for a budget increase for fisheries survey infrastructure. This increase in infrastructure funding will ensure regions like the EBS continue to be monitored and assessed into the future. Simultaneously, the AFSC is utilizing a combination of management strategy evaluation frameworks and comparisons between design-based and model-based abundance and variance estimators to identify the potential impacts of changing survey frequency, biological sampling methods and survey design on fish and crab stock assessments. AFSC is also exploring opportunities for expansion of standard fisheries and combined fisheries/oceanographic surveys to include physical and biogeochemical sampling to provide synoptic snapshots of LMR distribution and abundance within an ecosystem context and to most cost-effectively utilize surveys. The expanded sampling can also be used for model validation and skill testing in support of the regional or modular ocean models.

Expansion of moored observatories to the northern Bering Sea: PMEL (EcoFOCI) has maintained four long-term bio-physical moorings in the Bering Sea: M2 (26 years); M4 (23 years); M5 (17 years) and M8 (17 years). These moorings will continue to be maintained. In addition, a fifth site (M14) has been established north-east of St. Lawrence Island. M2 and M8 have been upgraded to include cutting edge technology.

OAR eDNA moorings and shipboard measurements (2022-2023): PMEL has submitted a proposal to OAR to continue eDNA research at the lab. The overarching goal for this proposal is to quantify changes in the Arctic (Bering and Chukchi seas) ecosystems using both moored and shipboard measurements of eDNA. More specific objectives include monitoring changes in phytoplankton community structure, monitoring population shifts in fish and shellfish species, improving detection methods for marine mammals, monitoring changes in nutrient cycling, monitoring for the presence of Harmful Algal Blooms (HABs), and monitoring changes in zooplankton distributions. There will be significant collaboration with the AFSC's eDNA program.

Key Needs

Although the AFSC has made great strides towards addressing all aspects of the NCSS (see Peterson et al. 2021), 25 key gaps remain that impede progress towards the delivery of climate informed reference points, robust harvest strategies, and climate-informed adaptation strategies (Table 3).

Table 3. -- Summary of the key gaps in climate-related research portfolio for the eastern Bering Sea (see Appendix for detailed project descriptions).

Focus Areas	**Total Projects**
Monitoring	12
Process Studies*	2
Management-Oriented Synthesis	5
Marine Mammals	2
Socioeconomics	4
Total	25

*Process-oriented surveys are included in Monitoring

Given the strong emphasis on integrated research for the EBS region, it was challenging to attempt to prioritize individual projects. Three research foci emerged that, when viewed within the context of the full suite of new and continuing research, would accelerate progress toward a fully integrated climate portfolio for the region. These three foci were as follows: Infrastructure (unfunded needs for surveys, process studies, and staff); Decision Support Pathways (modeling, data access to management, coordination, and communication); and New Technology.

New Technology for Fisheries and Oceanographic Research

NOAA is a leader in the development and deployment of advanced technologies that provide effective and efficient collection of physical, chemical, biological, and vessel movement data (Fig. 3). These technologies are particularly important for high-latitude marine ecosystems where weather conditions pose particularly challenging and expensive conditions for ship-board data collections. Through the long partnership between PMEL and the AFSC, many technological advancements have been successfully developed, tested, and deployed. Many of these advances are highly relevant to the EBS RAP 2.0. Several next generation sensors are now deployed on mooring M2 (https://www.pmel.noaa.gov/co2/story/M2+OA+Mooring) including: a nitrate sensor and Prawler (https://www.pmel.noaa.gov/edd/pmel-theme/prawler) to measure the water column continuously. Mooring M8 also includes a sediment trap, eDNA sampler, bag sampler, nitrate sensor, chromophoric dissolved organic matter (CDOM), and a "pop-top" to measure the top 20 m of the water column when ice is not present. Mooring M14 will contain a RiSE mooring. This new technology is a surface mooring that sinks with arrival of ice and rises to the surface with ice retreat and measures temperature, salinity, fluorescence, oxygen, and photosynthetically active radiation (PAR). In addition, there is a sensor that measures ice thickness and a camera to record the benthic community. All sites will include passive acoustics sensors needed to assess year-round seasonal occurrence of marine mammals.

Advanced technology offers excellent opportunities to address key information gaps for marine mammals and helps to modernize marine mammal assessments in Alaska. Key gaps include the need for AI to streamline processing of image and acoustics data in order to provide data products to managers on a timeline relevant for management decisions. Through national and international research collaborations, new platforms (e.g., uncrewed vehicles, aerial surveillance, and satellites) have been used to assess marine mammals and pollock movements (https://www.fisheries.noaa.gov/feature-story/collaboration-and-partnerships-make-data-collection-possible-challenging-year-arctic). In 2020, uncrewed surface vehicles (USVs) equipped with acoustics were used to survey the summer distribution of pollock in the Bering Sea (https://www.fisheries.noaa.gov/feature-story/autonomous-vehicles-help-scientists-estimate-fish-abundance-while-protecting-human; De Robertis et al. 2021). Upward-facing acoustic moorings have been used to assess transboundary fish movements. While considerable progress has been made on these issues, primarily using temporary funds from NMFS or from OAR, full transition to operations requires substantial and sustained support. Staff with new types of expertise, such as data scientists and programmers are needed to provide a technical interface between data collection and the new advanced tools used by the agency. In addition, continual investments in equipment, such as new uncrewed systems and passive acoustic recorders, are needed because existing equipment is dated and needs to be replaced on a rotating cycle or risk failure during deployment and subsequent loss of data. Technological advancements in underwater imagery when combined with artificial intelligence hold great potential for expanding standard survey data collections to include information on zooplankton communities.

Figure 3. -- Schematic of current and proposed technology deployment for the eastern Bering Sea.

Key Gaps in Infrastructure (NCSS Objectives 5-7)

The following key gaps all require infrastructure changes to sustain monitoring of climate change impacts on LMRs: Key Gaps for Monitoring (Appendix KGM 1-8), Key Gaps for Process Studies (Appendix KGP 1 and 2); and Key Gaps for Marine Mammals (Appendix KMM 1 and 2). These projects require supplemental funds for fishery-independent surveys and laboratory studies. Funding for these projects is needed along with additional funding to implement the CEFI Decision Support System.

Air and sea temperatures have been increasing rapidly, leading to cascading impacts that threaten the productivity and sustainability of Alaska's marine resources. Increased support for ecosystem data collection is needed and several critical gaps were identified. There is a distinct lack of knowledge of phytoplankton bloom timing, seasonality, and species composition, yet these measurements have been strongly linked to overall fisheries production across other marine systems. Further, the significant lack of microzooplankton data were identified as another concern in understanding ecosystem function. Microzooplankton are the primary grazers of the phytoplankton community and shifts in their composition, grazing rates, or size structure all

serve as indicators of changing trophic dynamics. These functional relationships governing predator and prey dynamics are needed to understand and predict the distribution, survival, and growth of managed resources. Similarly, several key gaps exist concerning zooplankton community structure and forage fish (primarily juvenile gadids) dynamics. Ship time is needed to support mooring deployment and oceanographic sampling to verify zooplankton (NPZ) models. Expansion of summer acoustic surveys into the inner domain will be needed to track prey dynamics of euphausiids and forage fish to verify and calibrate biological models used to simulate processes underlying shifting distributions and abundances of marine mammals, fish, and crab. Expanded monitoring of Harmful Algal Blooms (HABs) from moorings are needed to protect human health.

As species distributions shift in response to climate change, gaps in the spatial and temporal coverage of existing monitoring efforts have emerged. This gap could be addressed by expanding survey areas or spatial coverage and international data sharing partnerships, and expanding spatial temporal modeling efforts. This expansion can be achieved by increasing support for survey vessels and staff, but it is likely that achieving these objectives will also require redistribution of effort facilitated by increases in efficiency of existing surveys (e.g., redistributing effort on the EBS shelf bottom trawl survey to enable bottom trawl sampling of the EBS slope and northern Bering Sea with regular periodicity). Therefore, addressing this gap will require the development and testing of analytical tools for redesigning surveys, validation and feasibility evaluation of alternative observational methods (e.g., new technologies such as eDNA), and support for automating data collection, processing, and dissemination.

Support is needed to expand ocean and biogeochemical sampling in the NBS to track changes in the coupling between the benthos and the pelagic ecosystems. A broad suite of sampling improvements including expanded collection of nutrients, oxygen, and pH on moorings is needed. In response to warming ocean conditions and reductions in seasonal sea ice thickness and extent, the NBS ecosystem is expected to shift to a system capable of supporting sub-arctic pelagic foragers (borealization). Pelagic-benthic coupling relationships in the EBS remain poorly understood but are changing rapidly. Increased support for these activities and other similar cross-trophic collections will provide much-needed understanding of ecosystem-modulated fisheries production.

Research to assess climate-mediated demographic vulnerability of core species is needed to understand climate-sensitive recruitment bottlenecks, including reproduction, early life development, body condition, foraging and provisioning, and spatial shifts. Specifically, field and laboratory studies that resolve thermal effects on prey community composition and foraging, lipid storage and provisioning, and overwinter survivorship will be needed to provide climate-informed reference points for end-to-end models, increasing model predictive power and accuracy. We will also conduct research and development on advanced technology to improve

sampling efficiency (uncrewed systems) for early life stages and sampling seasonality (winter) to provide more, better, and previously unavailable data to ecosystem model suites.

Climate change is expected to impact predator prey interactions through changes in bioenergetics (ocean warming), foraging-bout frequency and distance, and the energetic quality of key prey. Decreased funding resources have reduced sample collection and processing at a time when improved data collections for core species are required to assess impacts of climate change. Stabilizing funding for laboratory studies (bioenergetics, species composition of the diet, size spectrum of the diet) and an archival database to provide a permanent repository for sample data collected in the field will add value to the AFSC's ecosystem monitoring and modeling efforts.

Increased survey frequency of Alaska pinnipeds will improve MMPA stock assessments by enabling regular monitoring for abundance, trends, and breeding distribution on a rotational basis: a 6-year cycle of biennial surveys of phocids in each of the Bering, Chukchi, and Beaufort seas and a 2-5-year survey cycle for otariids in the Bering Sea and Aleutian Islands. The various species of Alaska pinnipeds will be impacted differently by predicted climate changes and those changes can only be monitored and evaluated through systematic collection of abundance, distribution, and other ecological information. Sea level rise, loss of terrestrial and sea ice habitats required by pinnipeds, warming and other oceanographic changes, and redistribution of prey resources can be expected to impact marine mammals. Reliable and regular monitoring of marine mammals will support NMFS priorities for climate-resilient fisheries and Alaskan communities.

Information on abundance and trends of cetacean stocks is needed to understand the impacts of a changing climate on these protected species. At this time, current abundance is available for 53% of cetacean stocks throughout Alaska, and trends are available for 15% of cetacean stocks; the Bering Sea is part of the range of many of these stocks, yet no dedicated surveys for cetacean abundance have occurred in this area since 2006. The proposed Arctic Marine Assessment Program for Protected Species (ArMAPPS) includes a suite of projects focusing on abundance, distribution and trends of cetaceans in the Bering Sea using vessel-based, aerial, and passive acoustics approaches that together would substantially improve the information available for managers to understand how cetacean populations are responding to their environment and to anthropogenic activities. This program would be modeled after highly successful programs in the Pacific (PacMAPPS) and Atlantic (AMAPPS) and would involve rotating surveys to assess abundance, distribution, and stock structure of cetaceans and expedited processing of data to provide information to managers.

Key Gaps in Pathways for Decision Support (NCSS Objectives 1-4)

The following key gaps in pathways for Fisheries and Climate Decision Support were identified: Key Gaps for Monitoring (Appendix KGM 10-12), Key Gaps for Management-Oriented Synthesis (Appendix KGMOS 1-5); and Key Gaps for Socioeconomics (Appendix KGS 1-5).

Many of these key gaps would be addressed through full implementation of the CEFI. Collectively these projects address key uncertainties in the Fisheries and Climate Decision Support System for the EBS.

The ACLIM phase 2 project in conjunction with the CEFI is expected to provide operational decision support tools and reports for use in climate impact assessments, tactical decision making and strategic planning. Through targeted hiring, reliable delivery of high-resolution ocean simulations, operationalization of the socio-ecological modeling suite and development of user-friendly data portals, the CEFI is expected to stabilize the pathway from ecosystem observations to management decisions. An expansion of the suite of ecosystem and socioeconomic indicators enabled by the delivery of reliable and verifiable high-resolution ocean model products at multiple time scales (sub-seasonal, seasonal to decadal) will allow analysts to tailor the indices used in ESPs, ESRs, and Risk Tables to specific ecosystem linkages. The CEFI will create data portals that can be synced with current data management applications of the ESPs and ESRs that are integrated with the current stock assessment process. This will allow for a transparent evaluation process from indicator development to testing candidate indicators for ecosystem-linked assessments. The combination of new monitoring and process study research activities, the coordinated data portals, and high-resolution ocean model products is expected to accelerate the development of climate-ready management products. The CEFI will provide the necessary personnel to track evolving improvements in mechanistic understanding and stock thresholds to inform management and adaptation response. Results from projects supported by the CEFI, Phase 2 of ACLIM and Bering Seasons Project may be critical for understanding future implications of climate change. Coordination between these efforts needs to be maintained and supported so that downstream management decisions are based on the best scientific information available.

Standardized approaches to processing and dissemination of data (particularly environmental data) and their derived products are needed to accelerate the uptake of climate data. Furthermore, coordination of current and future activities would improve the efficiency of research and monitoring efforts by increasing the scope of data collected by an individual project (e.g., via incorporation of multiple observation types and collection methods on a given survey, including those enabled by new technologies).

To develop future EBS-RAPs, the AFSC will take steps to strengthen existing relationships and continue to expand reciprocal relationships with Alaska Native communities and fishing communities in the Bering Sea. AFSC researchers will work together with members of coastal fishing and Alaska Native communities as they identify mutual priorities for research 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. NMFS will expand opportunities to advance Environmental Justice in its research through

consistent and sustained engagement and collaboration with Alaska Native communities to co-produce marine research to better inform management of living marine resources.

AFSC's new Tribal Research Coordinator will assist by communicating information about the AFSC research mission and helping to advance a two-way dialogue to strengthen working relationships and build partnerships between researchers and Alaska subsistence hunters, fishers, and community members. The initial focus will be on the northern Bering Sea, where loss of sea ice, shifting fish stocks, and changing environmental conditions are profoundly affecting Alaska Native communities. We plan to coordinate closely with the Nome-based NOAA Sea Grant Marine Advisory Program (MAP) agent and Alaska Native organizations in the region to broaden awareness of this effort.

To build broader awareness of the AFSC mission, other communications efforts are expected to coincide with this effort including 1) radio interviews and local newspaper features and 2) educational efforts. As appropriate, we will also use NMFS communications platforms to highlight collaborative efforts (website, Facebook, and other social media platforms regionally and nationally).

Investments in understanding human community adaptations to climate change are needed. Funding is currently limited and only sporadically available through temporary funds and research proposals. To more fully assess the adaptive capacities of dependent human communities, additional funds are needed to understand socioeconomic responses to changing conditions in order to gain knowledge of the functional relationships governing fish, shellfish, and marine mammal responses to changing climate.

Estimates of non-market conservation values of the Bering Sea Ecosystem are also needed. Previous research on the non-market values of Steller sea lions (SSLs) has demonstrated that residents throughout the Nation place a large value on reducing threats to endangered species such as SSLs. Because there are not market values for much of the value derived by Americans from protecting endangered marine mammals, seabirds, and the ecosystem as a whole, carefully designed surveys are required to estimate the benefits that people experience from a healthy ecosystem. More research is needed to understand the values and priorities from different degrees of environmental protection, especially in the face of a changing environment. This is an essential element in making good management trade-offs that balance diverse uses of the Bering Sea ecosystem.

By 2024, the AFSC will seek to provide the climate change and fisheries decision support information outlined in the NPFMC's Climate Change Task Force (CCTF) of the FEP and the NOAA CEFI. Products derived from this effort will provide timely information to the NPFMC and the AKRO regarding cumulative effects resulting from both short-term changes and long-term shifts in the abundance and distribution of federally managed species (Hollowed et al. 2020, Holsman et al. 2020, Reum et al. 2020, CCTF). The AFSC will also provide information to the

AKRO and other partners regarding vulnerability of marine mammals and other protected species and fishery-dependent communities to a changing climate.

Key Actions

Given the emerging opportunities expected, two scenarios were considered with respect to key actions relevant to the NCSS. Scenario 1 represents the base funding outcome. Scenario 2 assumes full funding of the projects outlined in the emerging opportunities section.

Scenario 1 Base Funding - New Initiatives not Funded

AFSC will strive to maintain its existing research portfolio. Erosion of base funds are likely to impede progress toward fully operationalizing Fishery and Climate Decisions Support Systems. Funding for ACLIM - Phase 2 and Bering Seasons Phase 2 will be discontinued and the projects will end in fiscal year (FY) 23 or FY 24. Slope surveys are likely to be discontinued, juvenile fish surveys will become biennial or severely reduced, and expansions of surveys into the near coastal regions will not occur (Appendix project *M1*).

The observer program and expanded implementation of electronic monitoring will continue (Appendix project *M2*).

A modest increase in the number of age determinations may be realized as FT-NIR spectroscopy methods are accepted for ageing some groundfish (Appendix project *M3*).

The Modeling, Analysis, Predictions and Projections (MAPP) project to conduct NPZ model calibration and skill assessment will be completed (Appendix project *P8*). PMEL will begin the transition from Regional Ocean Modeling System (ROMS) to Modular Ocean Model 6 (MOM6) models (Appendix project *MOS8*). eDNA research and development will continue. Shipboard oceanographic sampling will continue; however, erosion of funds may diminish the coverage and slow data processing and analysis. Three moorings (M2, M5 and M8) will be deployed and data will be collected along the 70-m isobath during mooring deployment (Appendix project *M8*).

The existing stock assessment (Appendix projects *MOS1-MOS6*), species distribution modeling (Appendix project *MOS7*) and some socioeconomic products will continue to be delivered to the NPFMC. All of these projects will suffer from insufficient mechanistic understanding, sub-optimal sampling, inefficient data delivery systems, and insufficient staffing and infrastructure to fully operationalize the fishery and climate decision support systems.

Scenario 1: Maintaining Mechanistic Research, Infrastructure, and Tracking Change (NCSS Objectives 5-7)

- **Base Funding Action 1:** Maintain core fisheries independent survey efforts in the eastern Bering Sea including the bottom trawl surveys (NBS, EBS), the summer acoustic - trawl

survey (EBS), and targeted process-oriented fisheries oceanographic survey. Maintain model-based (such as vector autoregressive spatio-temporal (VAST) models) survey biomass estimates. Evaluate implications of current and alternative survey sampling designs. Maintain pinniped surveys and analyze passive acoustics for presence absence of cetaceans. (NCSS Objective 6)

- **Base Funding Action 2:** Maintain and improve fishery monitoring and assessment program and evaluate implications of adoption of electronic monitoring (EM) on stock assessments. (NCSS Objective 6)
- **Base Funding Action 3:** Deploy moorings and invest in new technologies to enhance data collection from existing survey platforms. (NCSS Objective 7)
- **Base Funding Action 4:** Assess fishery dependent community responses to climate-induced ecosystem change. Produce ACEPO reports and Economics SAFE. (NCSS Objective 6)
- **Base Funding Action 5:** Conduct laboratory and field research on the mechanistic effects of multiple climate factors (e.g., temperature, ocean acidification, dissolved oxygen) on living marine resources with the goal of informing process-based models for single species, multi-species, and the ecosystem. (NCSS Objective 5)
- **Base Funding Action 6:** Conduct ecosystem surveys of the EBS and NBS for assessing physics, phytoplankton, zooplankton, and larval, juvenile fish abundance and condition as allowed by funding constraints. (NCSS Objective 6)

Scenario 1: Pathways to Inform Climate, Ecosystem and Fisheries Decision Support Systems (NCSS Objectives 1-4)

- **Base Funding Action 7:** Continue production of annual stock assessments, ESRs, ESPs, Risk Tables, and CCTF products that include climate relevant information. (NCSS Objectives 1, 6)
- **Base Funding Action 8:** Improve spatial management of living marine resources through an increased utility of spatial and temporal distributions, abundance, migration, and phenology in management decisions. Complete EFH 5-year review using next generation spatial-temporal species distribution models. Investigate movement patterns of invertebrate, fish, mammal and bird populations through conventional and electronic tagging technologies to examine responses to climate change. (NCSS Objective 3)
- **Base Funding Action 9:** Complete Management Strategy Evaluation (MSE) and Scenario Planning as proposed in ACLIM - Phase 2. Deliver reports on the trade-offs of current and alternative management and adaptation strategies under various climate change scenarios. Scenarios will include re-evaluation of system level optimum yield (OY) groundfish cap and trade-offs in changing cap. (NCSS Objective 2)
- **Base Funding Action 10:** Work with NOAA Oceanic and Atmospheric Research, National Weather Service, the National Ocean Service, and academic partners to develop and improve regional hindcasts, forecasts, and projections of ocean and estuarine/river

physics and biogeochemistry. Deliver skill assessments of short-term forecasts and produce long-term climate projections using selected Coupled Model Intercomparison Project (Phase 6) (CMIP 6) global model scenarios (ACLIM Phase 2) (NCSS Objective 4)

- **Base Funding Action 11:** Increase social and economic scientist involvement in climate change research through multidisciplinary research on climate that includes both social and natural sciences. (NCSS Objective 4, 5)
- **Base Funding Action 12:** Transition at least one assessment from the semi-quantitative statistical analysis of ecosystem indicators in ESPs to an operational ecosystem - linked stock assessment model. Implement one assessment using Fisheries Integrated Modeling System software. (NCSS Objective 1)

Impact to Science and Agency Decision Makers of Scenario 1

The agency will continue to rely on temporary funding for multiple projects, particularly those that advance NMFS' ability to build fishery and climate decision support systems into the future. Lack of sampling in the slope region and irregular sampling in the NBS will reduce the Agency's ability to track impacts of climate change on LMRs. Likewise, reduced process studies and intermittent sampling of ichthyoplankton and age-0 pollock populations retard the pace at which mechanistic understanding advances.

Scenario 2 - Initiatives Funded

The pending new opportunities will address many of the key gaps identified. The four initiatives are particularly relevant to the EBS RAP as they address key infrastructure (staffing and ship time) needed to sustainably expand surveys into the Northern Bering Sea and deliver fishery and climate decision support to fishery-dependent communities and managers. The influx of base funding will allow the AFSC to expand survey teams to accommodate this new and challenging monitoring need.

- **Scenario 2 Action 1:** OAR's Arctic initiative and NOAA's Infrastructure initiative, NOAA will expand its physical and biological sampling of the NBS and Chukchi Sea to improve our understanding of the borealization of the high latitude marine ecosystems in the region. All planned moorings will be deployed with next generation technology and new technologies will be deployed to enhance data collection from existing survey platforms.
- **Scenario 2 Action 2:** Through the CEFI, operationalize the delivery of high spatial and temporal resolution ocean hindcasts, nowcasts, forecasts and projections launching a new era of climate, ecosystem and fisheries research where scientists can track ecosystem change continuously through time rather than depending on snapshots of information.
- **Scenario 2 Action 3:** OAR will hire key permanent personnel through the CEFI. New staff and information portals will ensure reliable access to derived ocean products

(information portals) and the continuation of innovations to improve socio-ecological models.

- **Scenario 2 Action 4:** Through the CEFI NOAA will bolster and stabilize regional modeling capabilities at PMEL and the AFSC by adding key permanent personnel to expand, enhance and sustain the delivery of historically verified, high-resolution year-round ocean products that are incorporated in coupled socio-ecological models of different complexity to routinely deliver ecosystem-linked assessments (tactical) and climate-enhanced stock and ecosystem projections (strategic). Reliable access to derived ocean products will improve the quality and applicability of indicators used to assess ecosystem status (ESRs) or stock condition (ESPs). Development of the Fisheries Integrated Modeling System will provide new tools for the exploration of ecosystem-linked assessments. Stabilizing funding for the GOA CLIM and ACLIM Phase 2 projects and transitioning from temporary personnel to permanent personnel, will supplement existing social and ecological modelers at AFSC to identify climate-sensitive criticalities for economically and ecologically important ("core") fish species. Economically important species will include target species (e.g., Pacific cod, pollock, sablefish, crab) and choke species (e.g., Pacific halibut, salmon). Ecologically important species will include forage species and early life stages identified as limiting or shifting resources in Alaska marine ecosystems (e.g., euphausiids, capelin).
- **Scenario 2 Action 5:** The CEFI funding for permanent personnel will allow the delivery of ecosystem-linked single- and multi-species assessments and full life cycle spatial models that include climate impacts across life history stages in the GOA and EBS. These new models will enable analysts to track, forecast and project the vulnerability or core species as they age and develop. These full life cycle, spatial models (e.g., Individual-Based Models or full end-to-end ecosystem models) will provide a platform for the evaluation of the predictive skill of mechanisms linking climate and LMRs and will provide rapid feedback and verification of RAP objective 5 processes.
- **Scenario 2 Action 6:** Through the CEFI, key permanent personnel will be hired to facilitate sustained engagement of fishery dependent communities and managers. As noted in Key Gaps, identifying adaptation pathways and evaluating the trade-offs associated with these pathways requires two-way communication between analysts and fishery-dependent constituents. The CEFI new hires will fill this critical role. We anticipate that the new hire will play an integral part in the CCTF, climate workshops and annual scientific reviews. The holistic nature of the CEFI (one NOAA approach) and the associated community of practice will break down communication barriers between historically isolated research teams between and within NOAA, AFSC, AKRO, the NPFMC, and our constituents.
- **Scenario 2 Action 7:** When CEFI funding is coupled with NMFS infrastructure funding and OAR's funding initiatives, scientists at the AFSC will be able to track, forecast, verify, and project the increased complexity of climate-driven ecological interactions, to

explain the accelerated rates of change being observed, and to resolve vulnerabilities, thresholds, and tipping points.

- **Scenario 2 Action 8:** NOAA's Infrastructure funding enhance AFSC's ability to utilize information from expanded field and laboratory studies (see KGM9) to 1) examine the mechanistic basis of these bottlenecks (e.g., physiological tolerances, dietary analyses, habitat preferences); 2) with funding from the infrastructure proposal, an expanded focus on forage dynamics will provide the necessary data for this modeling endeavor; and 3) the unfunded research in the nearshore to fill gaps in our understanding of coastal food webs, essential nursery habitats, and juvenile fish survival (such as delivery of fresh water and nutrients to marine ecosystems and associated effects on nearshore ocean chemistry).
- **Scenario 2 Action 9:** Project support will be needed to relieve the large administrative burden for the scientific leaders in this research area at the Center. This support will sustain the interdisciplinary focus of the program, by relieving permanent staff of administrative activities. By design and reality, ACLIM and the climate science efforts at the Center are not a single program or division, but a crosscutting effort that draws on the scientific skills and experience of all divisions of the Center. This action would create rotational assignments, internships and other creative ways to seek people to facilitate this cross-divisional research and improve the scientific output of the Center. These rotational assignments would address KGMOS5 and the incumbents would serve a scientific administrative and coordination role that would support the PIs of ACLIM, Gulf of Alaska Climate Integrated Modeling (GOA-CLIM), the CEFI, and related initiatives. Primary responsibilities would be organizing meetings, reporting, project and budget tracking, environmental data integration as needed, and internal communications (which would help address KGM 12). This would facilitate effective use of environmental data and products derived from these data.

Remaining Gaps Under Scenario 2

The following key gaps will not be addressed by funding from the requested funding initiatives:

- Food habits long-term data program.
- Nearshore ecosystems and juvenile fish population dynamics.
- Field and laboratory studies to resolve thermal effects on core species bottleneck process studies.
- Modernizing marine mammal research with incorporation of AI for large data sets (e.g. photographic and video imagery and acoustic data).
- Arctic marine mammal assessment program for protected species (ArMAPPS).
- Annual and biennial surveys of Steller sea lions and northern fur seals in Alaska.
- Euphausiid dynamics.

Key Metrics

A key challenge for the RAPs has been identifying avenues for measuring progress toward achieving the NCSS objectives. It is important to develop performance measures that are specific, measurable, attainable, relevant, and time-based or SMART (Doran 1981). If these key attributes are integral to the metrics of the RAPs, then we will increase our accountability and improve evaluation of our progress toward meeting the NCSS objectives. The following is a list of SMART metrics developed for the EBS-RAP organized by NCSS objective. If a metric can only be applied under Scenario 2 (Initiatives funded), then that will be specified in parentheses following the metric.

NCSS Objective 1 Climate-Informed Reference Points

- At least one proposal for consideration by the NPFMC of a suite of climate/environmental conditions sufficient to trigger tactical changes to harvest specifications and tested trade-offs of implementation by 2024 (Scenario 2 only).
- At least one proposal for a suite of climate/environmental conditions sufficient to trigger strategic changes to fishery management (Scenario 2 only).

NCSS Objective 2 Robust Management Strategies

- Formation of Decision Support Teams (DSTs) nationwide with the Alaska DST working to create a regionally relevant, national informed community of practice for integrated climate, ecosystem, and fisheries decision support (Scenario 2 only).
- Delivery of climate-enhanced single, multispecies and ecosystem models for CMIP 6 scenarios under current and alternative harvest strategies by 2025 (Scenario 2 only).
- Delivery of at least one new ecosystem-linked stock assessment by 2025.

NCSS Objective 3 Adaptive Management Processes

- At least one workshop on climate-related community priorities in a Western Alaska community.
- At least one Council workshop with fishery stakeholders to facilitate usage of AFSC climate-related products in seasonal fishery timing and activities (Scenario 2 only).

NCSS Objective 4 Robust Projections of Future Conditions

- Ensemble of projected impacts of climate change on core species abundance and catch from suite of models of different complexity under fishing and climate scenarios (ACLIM phase 2).
- Formation of a national ocean modeling community of practice (Scenario 2 only).
- Resolution of bloom timing discrepancy in ROMs (product of MAPP proposal).
- Demonstration of short-term projection capability (product of Bering Seasons Phase 2 project).
- Delivery of climate scenarios under CMIP 6 ROMS models by 2023.
- At least one ecosystem linkage vetted through the ESP is used to make a short-term forecast of population status 6-9 months ahead by 2024 (Scenario 2 only).

NCSS Objective 5 Information on Mechanisms of Change

- Research papers describing functional relationship between climate and fish or crab (Scenario 2 only).
- Research papers on threshold prey densities needed to sustain northern fur seals (ACLIM phase 2).
- Research paper showing implications of climate change on fisher behavior (ACLIM phase 2).
- Research paper on changes in pelagic-benthic coupling (Scenario 2 only).
- Research paper describing implications of climate change on fish growth (product of WGRAPHY).
- Presentations on results of process studies to national and international constituents.

NCSS Objective 6 Status, Trends and Early Warnings

- Delivery of ESPs to the NPFMC advisory bodies through the stock assessment process for at least five species every year.
- Delivery of ESRs to the NPFMC advisory bodies through the stock assessment process every year.
- Delivery of Annual Community Engagement and Participation Overview (ACEPO).
- Delivery of Economic SAFE reports for groundfish and crab every year.
- Delivery of stock assessments every year including risk tables.
- Delivery of VAST model estimates of biomass every year.
- Delivery of ocean mooring data every year.
- Delivery of underway oceanography every year.
- Delivery of euphausiid distribution and density every other year.

NCSS Objective 7 Science Infrastructure to Deliver Actionable Information

- Completion of EBS bottom trawl, acoustic and longline surveys.
- Completion of ichthyoplankton and age-0 surveys (increased under Scenario 2).
- Completion of marine mammal surveys.
- Maintain delivery of catch accounting and fishery-dependent sampling.
- Completion of age determinations.
- Deployment of underway oceanographic data collections during surveys (increased under Scenario 2).
- Completion of community surveys (Scenario 2 only).
- Deployment of moorings (increased under Scenario 2).

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Glossary of Terms

AACA – Adaptation Actions for a Changing Arctic
ABC – Acceptable Biological Catch
ACEPO – Alaska Community Engagement and Participation Overview
ACLIM – Alaska Climate Integrated Modeling, https://www.fisheries.noaa.gov/alaska/ecosystems/alaska-climate-integrated-modeling-project
ADF&G – Alaska Department of Fish and Game, https://www.adfg.alaska.gov/
AGP – Age and Growth Program, https://www.fisheries.noaa.gov/alaska/science-data/age-and-growth-research-alaska
AFSC – Alaska Fisheries Science Center, http://www.afsc.noaa.gov/
AKFIN – Alaska Fisheries Information Network, https://akfin.psmfc.org/
AKRO – Alaska Regional Office, https://www.fisheries.noaa.gov/about/alaska-regional-office
AMAP – Arctic Monitoring and Assessment Programme
AMAPPS – Atlantic Marine Assessment Program for Protected Specie
ArMAPPS – Arctic Marine Assessment Program for Protected Species
ATTACH – ABC To TAC and Commercial Harvest
AVO – Acoustic Vessels of Opportunity
BASIS – Bering Arctic and Subarctic Integrated Survey, https://www.fisheries.noaa.gov/alaska/population-assessments/bering-arctic-and-subarctic-integrated-survey
BEST – Bering Ecosystem Study
BKIBS – Bridging Knowledge to Inform Bering Sea Management
BS – Bering Sea
BSAI – Bering Sea and Aleutian Islands
BSFEP – Bering Sea Fishery Ecosystem Plan, https://www.npfmc.org/fishery-management-plan-team/bsfep/
BSIERP – Bering Sea Integrated Ecosystem Research Program, https://nprb.org/bering-sea-project/
CAS – Catch Accounting System, https://www.fisheries.noaa.gov/alaska/sustainable-fisheries/alaska-catch-accounting-system
CCTF – Climate Change Task Force
CDOM - chromophoric dissolved organic matter
CEATTLE - Climate-Enhanced, Age-based model with Temperature-specific Trophic Linkages and Energetics
CEFI – Climate, Ecosystems, and Fisheries Initiative, https://www.fisheries.noaa.gov/topic/climate-change#noaa-climate-and-fisheries-initiative
CGE – computable general equilibrium
CMIP 5 – Couple Model Intercomparison Project (Phase 5)
CMIP 6 – Couple Model Intercomparison Project (Phase 6)
COCA – Coastal and Ocean Climate Applications, https://cpo.noaa.gov/Divisions-

Programs/Climate-and-Societal-Interactions/The-Adaptation-Sciences-Program/COCA/About-COCA
CPO – Climate Program Office
DBO – Distributed Biological Observatory
DFO – Fisheries and Oceans Canada, https://www.dfo-mpo.gc.ca/index-eng.html
DSS – Decision Support Systems
DST – Decision Support Team
EBM – Ecosystem-Based Management
EBFM – Ecosystem-Based Fishery Management
EBS – Eastern Bering Sea
EcoFOCI – Ecosystems & Fisheries-Oceanography Coordinated Investigations, https://www.ecofoci.noaa.gov/
ECOHAB – Ecology and Oceanography of Harmful Algal Blooms, https://coastalscience.noaa.gov/science-areas/habs/ecohab/
eDNA – environmental Deoxyribonucleic Acid
EFH – Essential Fish Habitat
EM – electronic monitoring
ESA – Endangered Species Act, https://www.fisheries.noaa.gov/topic/endangered-species-conservation
ESP – Ecosystem and Socioeconomic Profile
ESR – Ecosystem Status Report
FATE – Fisheries and the Environment, https://www.st.nmfs.noaa.gov/fate/
FMA – Fisheries Monitoring and Assessment, https://www.fisheries.noaa.gov/about/fisheries-monitoring-and-analysis
FMP – Fishery Management Plan
FIMS – Fisheries Integrated Modeling System, https://www.fisheries.noaa.gov/national/population-assessments/fisheries-integrated-modeling-system
FT-NIRS – Fourier Transform Near Infrared Spectroscopy, https://www.fisheries.noaa.gov/feature-story/innovative-technology-promises-fast-cost-efficient-age-data-fisheries-management
FY – fiscal year
GAP – Groundfish Assessment Program, https://www.fisheries.noaa.gov/contact/groundfish-assessment-program
GFDL – Geophysical Fluid Dynamics Laboratory, https://www.gfdl.noaa.gov/
GKN – global knowledge network
GOA – Gulf of Alaska
GOA-CLIM – Gulf of Alaska Climate Integrated Modeling
GRP – Genetics Research Program, https://www.fisheries.noaa.gov/alaska/science-data/genetics-research-alaska-fisheries-science-center

HAB – Harmful Algal Bloom
HCD – Habitat Conservation Division
HI-EBFM – Human Integrated Ecosystem-Based Fishery Management, https://www.fisheries.noaa.gov/human-integrated-ecosystem-based-fishery-management-research-strategy-2021-2025-executive-summary
ICM – Indigenous Conceptual Model
ICES – International Council for the Exploration of the Seas, https://www.ices.dk/about-ICES/Pages/default.aspx
IEA – Integrated Ecosystem Assessment, https://www.integratedecosystemassessment.noaa.gov/regions/alaska
IERP – Integrated Ecosystem Research Program, https://www.nprb.org/nprb/integrated-ecosystem-research-program
IPCC – Intergovernmental Panel on Climate Change, https://www.ipcc.ch/
IPHC – International Pacific Halibut Commission, https://iphc.int/
LK – Local Knowledge
LKTKS – Local Knowledge/Traditional Knowledge/Subsistence
LKTKSTF – Local Knowledge/Traditional Knowledge/Subsistence Task Force
LMR – Living Marine Resources
LOSI – Loss of Sea Ice, https://www.fisheries.noaa.gov/alaska/ecosystems/habitat-and-ecological-processes-research-regarding-loss-sea-ice
MACE – Midwater Assessment and Conservation Engineering program, https://www.fisheries.noaa.gov/contact/midwater-assessment-and-conservation-engineering-program
MAP – Marine Advisory Program
MAPP – Modeling, Analysis, Predictions and Projections
MESA – Marine Ecology and Stock Assessment program, https://www.fisheries.noaa.gov/tags/marine-ecology-and-stock-assessment-program
MMPA – Marine Mammal Protection Act, https://www.fisheries.noaa.gov/national/marine-mammal-protection/marine-mammal-protection-act-policies-guidance-and-regulations
MOM6 – Modular Ocean Model 6
MRSAM – multi-regional social accounting matrix
MSA – Magnuson Stevens Fishery Conservation and Management Act, https://www.fisheries.noaa.gov/resource/document/magnuson-stevens-fishery-conservation-and-management-act%20the%20focus%20of%20our%20work,%20recognizing%20both%20the%20need%20to%20address%20environmental%20justice%20challenges%20and%20the%20need%20to%20properly%20balance%20the%20interests%20of%20diverse%20communities%20that%20rely%20on%20the%20Bering%20Sea%20environment.
MSE – Management Strategy Evaluation
NBS – northern Bering Sea

NCEP CFS – National Centers for Environmental Prediction Climate Forecast System, https://cfs.ncep.noaa.gov/
NCSS – NOAA Fisheries Climate Science Strategy, https://www.fisheries.noaa.gov/national/climate/noaa-fisheries-climate-science-strategy
NEPA – National Environmental Policy Act, https://www.noaa.gov/organization/information-technology/guidance-for-national-environmental-policy-act-nepa
NMFS – National Marine Fisheries Service, https://www.fisheries.noaa.gov/
NOAA – National Oceanic and Atmospheric Administration, https://www.noaa.gov/
NOA – National Ocean Service, https://oceanservice.noaa.gov/
NPFMC – North Pacific Fishery Management Council, https://www.npfmc.org/
NPZ – Nutrient Phytoplankton Zooplankton
NS – National Standard
OA – Ocean Acidification
OAR – Oceanic and Atmospheric Research, https://research.noaa.gov/
OY – Optimum Yield
PacMAPPS – Pacific Marine Assessment Program for Protected Specie
PAR – photosynthetically active radiation
PICES – North Pacific Marine Science Organization, https://meetings.pices.int/
PMEL – Pacific Marine Environmental Laboratory, https://www.pmel.noaa.gov/
PRD – Protected Resources Division
RAP – Regional Action Plan
REEM – Resource Ecology and Ecosystem Modeling, https://www.fisheries.noaa.gov/contact/resource-ecology-and-ecosystem-modeling-program
ROMS – Regional Ocean Modeling System
RPA – Recruitment Processes Alliance, https://www.fisheries.noaa.gov/alaska/ecosystems/ecosystem-and-recruitment-process-research-alaska
RRI – Rapid Response Indicator
RUSALCA – Russian American Long-Term Census of the Arctic
SAFE – Stock Assessment and Fishery Evaluation
SAIP – Stock Assessment Improvement Plan, https://www.fisheries.noaa.gov/feature-story/updated-stock-assessment-improvement-plan-builds-past-success
SAP – Shellfish Assessment Program, https://www.fisheries.noaa.gov/contact/shellfish-assessment-program
SDM – species distribution model
SEBSCC – Southeast Bering Sea Carrying Capacity, https://coastalscience.noaa.gov/project/southeast-bering-sea-carrying-capacity-ecosystem-study/
SF – Sustainable Fisheries Division, https://www.fisheries.noaa.gov/region/alaska#fisheries
SLI – St. Lawrence Island
SMART – specific, measurable, attainable, relevant, and time-based

SMARTNET – Sustainability of Marine Ecosystems through global knowledge networks
SPURF – Subsistence, Personal Use, and Recreational Fisheries
SROCC – Special Report on Oceans and Cryosphere in a Changing Climate, https://www.unep.org/resources/report/ipcc-special-report-ocean-and-cryosphere-changing-climate
SSL – Steller Sea Lion
SSMA – Status of Stocks and Multispecies Assessment, https://www.fisheries.noaa.gov/alaska/population-assessments/assessing-alaska-fish-stocks
TAC – total allowable catch
TK – Traditional Knowledge
TOR – Terms Of Reference
TSR – temperature-size rule
UNDOS – United Nations Decade on Ocean Science and Sustainable Development
VAST – vector autoregressive spatio-temporal
WGGRAFY – Working Group on Impacts of Warming on Growth Rates and Fisheries Yields

Citations

Beck, J., Michael, P. E., Hester, M., Nevins, H. M., Donnelly-Greenan, E., Gibble, C., Phillips, E. M., Young, C., and Fitzgerald, S. 2021. Seasonal variation of Pacific northern fulmar bycatch: Implications for age and sex-specific mortality. Fisheries Oceanography 30(3): 253-263.

Cheng, W., Hermann, A., Hollowed, A., Holsman, K., Kearney, K., Pilcher, D., Stock, C., and Aydin, K. 2021. Bering Sea dynamical downscaling: Environmental and lower trophic level responses to climate forcing in CMIP6. Deep-Sea Research II 193(104975). https://doi.org/10.1016/j.dsr2.2021.104975

De Robertis, A., Lawrence-Slavas, N., Jenkins, R., Wangen, I., Mordy, C. W., Meinig, C., Levine, M., Peacock, D., and Tabisola, H. 2019. Long-term measurements of fish backscatter from Saildrone unmanned surface vehicles and comparison with observations from a noise-reduced research vessel. ICES Journal of Marine Science 76 (7): 2459-2470.

De Robertis, A., Levine, M., Lauffenberger, N., Honkalehto, T., Ianelli, J., Monnahan, C., Towler, R., Jones, R. D., Stienessen, S., and McKelvey, D. 2021. Uncrewed surface vehicle (USV) survey of walleye pollock, *Gadus chalcogrammus*, in response to the cancellation of ship-based surveys. ICES Journal of Marine Science 78(8): 2797-2808. https://doi.org/10.1093/icesjms/fsab1155.

Doran, G. T. 1981. There's a S.M.A.R.T. way to write management's goals and objectives. Management Review 70(11): 35–36.

Dorn, M. W., and Zador, S. 2020. A risk table to address concerns external to stock assessments when developing fisheries harvest recommendations. Ecosystem Health and Sustainability 6(1): 1813634. DOI: 10.1080/20964129.2020.1813634.

Guthrie, C. M. III, Nguyen, Hv. T., Marsh, M., Watson, J. T., and Guyon, J. R. 2020. Genetic stock composition analysis of the Chinook salmon (*Oncorhynchus tshawytscha*) bycatch from the 2018 Bering Sea pollock trawl fishery. U.S. Department of Commerce, NOAA Technical Memorandum NMFS-AFSC-407, 32 p.

Haynie, A. C., and Pfeiffer, L. 2013. Climatic and economic drivers of the Bering Sea walleye pollock (*Theragra chalcogramma*) fishery: Implications for the future. Canadian Journal of Fisheries and Aquatic Sciences 70(6): 841-853. https://doi.org/10.1139/cjfas-2012-0265

Healy, J., Helser, T. E., Benson, I. M., and Tornabene, L. 2021. Aging Pacific cod (*Gadus macrocephalus*) from otoliths using Fourier-transformed near-infrared spectroscopy. Ecosphere 12(8): e03697. https://doi.org/10.1002/ecs2.3697.

Hermann, A. J., Kearney, K., Cheng, W., Pilcher, D., Aydin, K., Holsman, K. K., and Hollowed, A. B. 2021. Coupled models of projected regional change in the Bering Sea from a dynamically downscaling model under CMIP6 forcing. Deep Sea Research II. Special Issue. 194: 104974. https://doi.org/10.1016/j.dsr2.2021.104974

Hermann, A. J., Gibson, G. A., Cheng, W., Ortiz, I., Aydin, K., Wang, M., Hollowed, A. B., and Holsman, K. K. 2019. Projected biophysical conditions of the Bering Sea to 2100 under multiple emission scenarios. ICES Journal of Marine Science 76(5):1280-1304. https://doi.org/10.1093/icesjms/fsz043.

Hollowed, A. B., Holsman, K. K., Haynie, A., Hermann, A., Punt, A., Aydin, K., Ianelli, J., Kasperski, S., Cheng, W., Faig, A., Kearney, K., Reum, J., Spencer, P., Spies, I., Stockhausen, W., Szuwalski, C., Whitehouse, G. A., and Wilderbuer, T. 2020. Integrated modelling to evaluate climate change impacts on coupled social-ecological systems in Alaska. Special Issue on Global Change and the Future Ocean, Frontiers in Marine Science 6(775). https://doi.org/10.3389/fmars.2019.00775.

Holsman, K. K., Haynie, A., Hollowed, A. B., Hermann, A. J., Cheng, W., Faig, A., Ianelli, J., Kearney, K., Punt, A., and Reum, J. 2020. Ecosystem based fisheries management forestalls climate-driven collapse. Nature Communications 11:4579. https://doi.org/10.1038/s41467-020-18300-3.

Hunt, G. L. Jr., and Hirawake, T. (Eds). 2020. The lack of sea-ice cover and the northern Bering Sea marine ecosystem. Deep-Sea Research Part II 181-182.

Hurst, T. P., Copeman, L. A., Haines, S. A., Meredith, S. D., Daniels, K., and Hubbard, K. M. 2019. Elevated CO2 alters behavior, growth, and lipid composition of Pacific cod larvae. Marine Environmental Research 145: 52-65.

IPCC. 2019. IPCC Special Report on the Ocean and Cryosphere in a Changing Climate. Pörtner, H.-O., Roberts, D. C., Masson-Delmotte, V., Zhai, P., Tignor, M., Poloczanska, E., Mintenbeck, K., Alegría, A., Nicolai, M., Okem, A., Petzold, J., Rama, B., and Weyer, N.M. (Eds.). Intergovernmental Panel on Climate Change, Geneva Switzerland. https://www.ipcc.ch/srocc/

Land, C. A., Richar, J. I., and Foy, R. J. 2019. The 2018 eastern Bering Sea continental shelf and northern Bering Sea trawl surveys: Results for commercial crab species. U.S. Department of Commerce, NOAA Technical Memorandum NMFS-AFSC-386, 220 p. https://repository.library.noaa.gov/view/noaa/19575.

Lauth, R. R., Dawson, E. J., and Conner, J. 2019. Results of the 2017 eastern and northern Bering Sea continental shelf bottom trawl survey of groundfish and invertebrate fauna. U.S. Department of Commerce, NOAA Technical Memorandum NMFS-AFSC-396, 260 p.

Lew, D. K., Layton, D. F., and Rowe, R. D. 2010. Valuing enhancements to endangered species protection under alternative baseline futures: the case of the Steller sea lion. Marine Resource Economics 25(2): 133-154.

Link, J. D., Griffis, R., and Busch, S. (Eds.). 2015. NOAA Fisheries Climate Science Strategy. U.S. Department of Commerce, NOAA Technical Memorandum NMFS-F/SPO-155, 70 p.

Livingston, P. A., Aydin, K., Buckley, R. W., Lang, G. M., Yang, M., and Miller, B. S. 2017. Quantifying food web interactions in the North Pacific – a data-based approach. Environmental Biology of Fishes 100(4): 443-470.

McCarthy, A., Honkalehto, T., Lauffenburger, N., and De Robertis, A. 2020. Results of the acoustic-trawl survey of walleye pollock (Gadus chalcogrammus) on the U.S. Bering Sea Shelf in June - August 2018 (DY1807). AFSC Processed Rep. 2020-07, 83 p. Alaska Fish. Sci. Cent., NOAA, Natl. Mar. Fish. Serv., 7600 Sand Point Way NE, Seattle WA 98115. https://repository.library.noaa.gov/view/noaa/27293.

Meredith, M., Sommerkorn, M., Cassotta, S., Derksen, C., Ekaykin, A., Hollowed, A., Kofinas, G., Mackintosh, A., Melbourne-Thomas, J., Muelbert, M. M. C., Ottersen, G., Pritchard, H., and Schuur, T. 2019. Chapter 3: Polar Regions. In: Special Report on Oceans and Cryosphere in a Changing Ocean. Pörtner, H.-O., Roberts, D. C., Masson-Delmotte, V., Zhai, P., Tignor, M., Poloczanska, E., Mintenbeck, K., Alegría, A., Nicolai, M., Okem, A., Petzold, J., Rama B., and Weyer, N. M. (Eds.). Intergovernmental Panel on Climate Change, Geneva Switzerland. https://www.ipcc.ch/srocc/.

Ono, K., Haynie, A. C., Hollowed, A. B., Ianelli, J. N., McGillard, C. R., and Punt, A. E. 2018. Management strategy analysis for multispecies fisheries including technical interactions and human behavior in modeling management decisions and fishing. Canadian Journal of Fisheries and Aquatic Sciences 75(8):1185-1202.

Peterson, J., Griffis, R., Woodworth-Jefcoats, P., Jacobs, A., Hollowed, A., Farley, E., Duffy-Anderson, J., Dorn, M., Hurst, T., Moss, J., Rogers, L., Shotwell, K., Garfield, T., Zabel, R., deReynier, Y., Shott, E., Crozier, L., Bograd, S., Mantua, N., Samhouri, J., Quinlan, J., Gore, K., Muñoz, R., Leo, J., Waters, L., Burton, M., Saba, V., Borggaard, D., Ferguson, M., and Morrison, W. 2021. NOAA Fisheries Climate Science Strategy Five Year Progress Report. U.S. Department of Commerce, NOAA Technical Memorandum NMFS-F/SPO-228, 157 p.

Punt, A. E., Dalton, M. G., Cheng, W, Hermann, A. J., Holsman, K. K., Hurst, T. P., Ianelli, J. N., Kearney, K. A., McGilliard, C. R., Pilcher, D. J., and Veron, M. 2021. Evaluating the impact of climate and demographic variation on future prospects for fish stocks: An application for northern rock sole in Alaska. Deep Sea Research Part II: Topical Studies in Oceanography 189-190: 104951.

Reum, J., Blanchard, J. L., Holsman, K. K., Aydin, K., Hollowed, A. B., Hermann, A., Cheng, W., Faig, A., Haynie, A., and Punt, A. E. 2020. Ensemble projections of future climate change impacts on the eastern Bering Sea food web using a multispecies size spectrum model. Special Issue on Global Change and the Future Ocean, Frontiers in Marine Science 7(124). doi: 10.3389/fmars.2020.00124.

Seung, C. K., Dalton, M. G., Punt, A. E., Poljak, D., and Foy, R. 2015. Economic impacts of changes in an Alaska crab fishery from ocean acidification. Climate Change Economics 06(04): 1550017.

Seung, C., and Ianelli, J. 2016. Regional economic impacts of climate change: A computable general equilibrium analysis for an Alaska Fishery. Natural Resource Modeling 29(2): 289-333.

Seung, C. K., and Ianelli, J. N. 2019. Evaluating alternative policies for managing an Alaska pollock fishery with climate change. Ocean & Coastal Management 178: 104837.

Shotwell, S.K., Blackhart, K., Cunningham, C., Fissel, B., Hanselman, D., Lynch, P., and Zador, S. Accepted. Introducing the Ecosystem and Socioeconomic Profile, a proving ground for next generation stock assessments. Coastal Management.

Sigler, M., Hollowed, A., Holsman, K., Zador, S., Haynie, A., Himes-Cornell, A., Mundy, P., Davis, S., Duffy-Anderson, J., Gelatt, T., Gerke, B., and Stabeno, P. 2016. Alaska Regional Action Plan for the Southeastern Bering Sea. NOAA Fisheries Climate Science Strategy. U.S. Department of Commerce, NOAA Technical Memorandum, NMFS-AFSC-336, 51 p.

Siddon, E. (Ed.). 2020. Ecosystem Status Report 2020 Eastern Bering Sea. North Pacific Fishery Management Council, 1007 West Third, Suite 400, Anchorage, AK 99501.

Simonsen, K. A., Ressler, P. H., Rooper, C. N., and Zador, S. G. 2016. Spatio-temporal distribution of euphausiids: an important component to understanding ecosystem processes in the Gulf of Alaska and eastern Bering Sea. ICES Journal of Marine Science 73(8): 2020-2036. https://doi.org/10.1093/icesjms/fsv272.

Spies, I., Gruenthal, K. M., Drinan, D. P., Hollowed, A. B., Stevenson, D. E., Tarpey, C. M., and Hauser, L. 2020. Genetic evidence of a northward range expansion in the eastern Bering Sea stock of Pacific cod. Evolutionary Applications 13(2), 362-375. https://doi.org/10.1111/eva.12874.

Stabeno, P. J., Bell, S. W., Bond, N. A., Kimmel, D. G¸ Mordy, C. W., and Sullivan, M. E. 2019. Distributed Biological Observatory Region 1: Physics, chemistry and plankton in the northern Bering Sea. Deep Sea Research Part II: Topical Studies in Oceanography 162: 8-21.

Thorson, J. T., Barbeaux, S. J., Goethel, D. R., Kearney, K. A., Laman, E. A., Nielsen, J. L., Siskey, M. R., Siwicke, K., and Thompson, G. 2021. Estimating fine-scale movement rates and habitat preferences using multiple data sources. Fish and Fisheries 22(6): 1359-1376. https://doi.org/10.1111/faf.12592.

Wallmo, K., and Lew, D. 2010. An Application of Stated Preference Non-Market Valuation to Value Improvements to Threatened and Endangered Species. *In* Proceedings of the Fifteenth Biennial Conference of the International Institute of Fisheries Economics & Trade, July 13-16, 2010, Montpellier, France: Economics of Fish Resources and Aquatic Ecosystems: Balancing Uses, Balancing Costs. Compiled by Ann L. Shriver. International Institute of Fisheries Economics & Trade, Corvallis, Oregon, USA, 2010.

Appendix: Funded or Likely to be Funded Research

Existing projects are briefly summarized below, organized by five themes: Monitoring, Process Research, Management-Oriented Synthesis, Marine Mammals, and Socioeconomics.

Monitoring Projects

Scientists within the Alaska Fisheries Science Center and the Alaska Regional Office collect, synthesize, and evaluate fishery-dependent and fishery-independent data to meet the mandates of the Magnuson Stevens Fishery Conservation and Management Act, Marine Mammal Protection Act, and Endangered Species Act. To meet these mandates, the AFSC devotes more than 80% of its resources toward catch accounting (M2), standard surveys, ageing, food habits, genetics, and stock assessments of fish, crab, and marine mammal populations.

M1. Fish and Crab Surveys - Continuing - (NCSS Objectives 6 and 7).

Fish and crab species are monitored by deploying annual standard bottom trawl surveys (Groundfish Assessment Program, GAP; Shellfish Assessment Program, SAP; Lauth et al. 2019, Lang et al. 2019), and biennial longline and acoustic-trawl (Midwater Assessment and Conservation Engineering Program, MACE; McCarthy et al. 2020) surveys. Standard groundfish data collections occur for abundance, age, size, diet, and genetics. Standard crab data collection efforts include abundance, size, shell condition, reproductive condition and disease prevalence. The MACE acoustic-trawl survey occurs biennially in even years. In addition, MACE generates an Acoustic Vessels of Opportunity (AVO) backscatter index of pollock abundance in collaboration with GAP. In addition to monitoring fish distribution and abundance, the MACE program collects and maintains information on the distribution and abundance of euphausiids, the single largest food source for zooplanktivorous marine species in the EBS. The simultaneous collection of fish and prey (euphausiid) community composition, and spatial dynamics are critical to informing and increasing the predictive capacity of our ecosystem-linked assessments and ecosystem models.

The northern Bering Sea (NBS) has been recently sampled annually as part of the Loss of Sea Ice (LOSI) initiative, while the EBS slope has not been sampled since 2016 but was historically sampled every 2 years. Acoustic-trawl surveys occur in the southeastern Bering Sea with coverage in Russian waters or other areas as priorities and resources allow. Biennial longline surveys (Marine Ecology and Stock Assessment, [MESA] program) occur in the EBS slope region, providing information about sablefish and other groundfish stock status in deep habitats from 200 to 1,000 m.

M2. Fisheries Monitoring and Assessment - Continuing - (NCSS Objectives 6 and 7)

Members of the Fisheries Monitoring and Analysis (FMA) Division train, brief, debrief, and oversee (https://www.fisheries.noaa.gov/alaska/fisheries-observers/fisheries-monitoring-and-analysis-division-north-pacific-observer-program-training) over 450 observers (https://www.fisheries.noaa.gov/alaska/fisheries-observers/north-pacific-observer-program) annually. These observers collect catch data on fishes, crabs and other invertebrates, birds, and mammals aboard fishing vessels and at onshore processing plants that are used for in-season management and scientific purposes such as stock assessments and ecosystem studies. Information derived from Electronic Monitoring (EM), fish tickets, and the observer program are incorporated into the Catch Accounting System (CAS) which is utilized by the Sustainable Fisheries Division (SF) of the Alaska Regional Office to monitor in-season catch to ensure commercial fishery catch and bycatch is managed within sustainable harvest targets and limits. Use of EM is expected to expand in the next 3 years and research is ongoing to assess the utility of this approach.

M3. Age, Growth and Diet Monitoring - Continuing - (NCSS Objectives 6 and 7)

Information on growth (Age and Growth Program, AGP), size-at-age, age and length composition, provide vital information needed to sustainably manage living marine resources in the EBS. In the next 3 years, next-generation ageing methods based on Fourier Transform Near Infrared Spectroscopy (FT-NIRS) of otoliths are expected to increase the efficiency of age determinations for fishes (Healy et al. 2021).

The AFSC's Resource Ecology and Ecosystem Modeling (REEM) program maintains a database of the food habits of North Pacific groundfish (Livingston et al., 2017). These diet data are used to evaluate bioenergetics, condition, and food web dynamics. Both prey size and frequency consumed are essential inputs for bioenergetic and ecosystem models used to estimate population level prey consumption.

M4. Marine Mammal Assessments - Continuing - (NCSS Objectives 6 and 7)

The Marine Mammal Laboratory conducts regular surveys of Steller sea lions and northern fur seals (biennial) and harbor seals (approximate 5-year interval) in the EBS. These surveys include adult and pup counts which provide critical information to track the demographics and overall population trends of these species under changing climate conditions.

M5. Seabird Bycatch and Encounters - Continuing - (NCSS Objectives 6, 7)

Seabird surveys have been historically conducted by observers aboard vessels of opportunity, including NOAA surveys, but funding for these exercises expires in 2021 (Beck et al., 2021).

M6. Standard Shipboard Oceanographic Collections for Ecosystem Monitoring - Continuing - (NCSS Objective 6).

Ecosystem trends are monitored through a combination of standardized groundfish, crab and marine mammal resource assessment surveys, fisheries observer collections, seabird surveys and fisheries oceanographic surveys (see https://www.fisheries.noaa.gov/alaska/ecosystems/alaska-fish-research-surveys). Data collected from these surveys and other supplemental data collections from ships of opportunity provide several ecosystem indicators.

NMFS standard bottom trawl and acoustic-trawl surveys integrate the collection of fisheries oceanographic information in their standard operating procedures. These surveys collect data necessary for estimating fish and crab abundance and size, abundance of other invertebrates, and euphausiids (acoustic surveys only). Furthermore, standard data collections include fish otoliths and stomach contents (bottom trawl surveys only), chlorophyll-a (acoustic-trawl surveys only), temperature profiles, underway surface temperature, salinity, and pH. Standardized bottom trawl surveys (AFSC Groundfish and Shellfish Assessment Programs, RACE) occur in the southeastern Bering Sea on an annual basis, with extensions as priorities and resources allow.

M7. Standard Ichthyoplankton and Juvenile Fish Monitoring - Continuing - (NCSS Objective 6)

The AFSC's Recruitment Processes Alliance, RPA, a cross-divisional and cross-line-office partnership between the AFSC and the Pacific Marine Environmental Laboratory (PMEL), has historically conducted a set of ecosystem and fisheries oceanography surveys in the spring (https://www.fisheries.noaa.gov/alaska/ecosystems/alaska-fish-research-surveys, conducted biennially in even years), summer (https://www.fisheries.noaa.gov/alaska/ecosystems/alaska-fish-research-surveys, conducted annually), and late summer (Bering Arctic and Subarctic Integrated Survey, BASIS, conducted biennially in even years). These integrated ecosystem surveys were conducted regularly with coverage over the majority of the northern and southeastern Bering Sea shelves, but more recently loss of ship time and sea days (FY20, FY21, FY22) has interrupted the time series (established in 1995) of ecosystem observations (phytoplankton, zooplankton, larval fish, juvenile fish, diets, ageing). Observational ecosystem data are critical to supporting and validating modeling efforts and the reduction of survey capacity (including number of sea days) jeopardizes our ability to monitor and understand changes in the Bering Sea.

M8. Oceanographic Moorings - Continuing - (NCSS Objective 6)

The Oceanic and Atmospheric Research's (OAR) Pacific Marine Environmental Laboratory deploys four biophysical oceanographic moorings located along the 70-m isobath and one north of St. Lawrence Island (Stabeno et al. 2019).

M9. Derived Products from Ecosystem Monitoring - Continuing - (NCSS Objective 5-6)

Insights regarding climate change effects are gleaned from monitoring data through research, development, and testing of indicators that measure changing ecological and environmental conditions over time and space. For example, ecosystem monitoring data products improve our understanding of species distribution, phenology, species interactions, and how these factors may be affected by environmental drivers. Design- and model-based indices of abundance and distribution of groundfish and crab, estimated from standardized assessment surveys (see project M1), quantify spatial and temporal changes of key stocks (primarily at the interannual timescale) and they are a critical input to stock assessments. These data, along with other sources of biological and environmental information, are used to define Essential Fish Habitat (EFH) through species distribution models (SDMs). Standard surveys also inform estimation of ecosystem indices such as the extent of the cold pool (the area of the eastern Bering Sea where summer bottom temperatures are less than or equal to 2° C, which is an important predictor of distribution and abundance for the demersal community) and stock-specific indices of productivity such as individual condition. Ongoing analyses are evaluating how changes to standard survey designs, aimed to improve efficiency and flexibility of surveys to adapt to shifting species distribution and survey costs and resources, are expected to influence the accuracy and precision of key survey data products. Fishery-dependent data form another primary input to stock assessments by providing catch magnitude and composition, and help inform spatial distribution and phenology by tracking the location and date of catches. Groundfish stomach contents collected during standardized surveys form the basis for developing diet time series informing the development of spatial and non-spatial models of predator-prey interactions for use in stock assessments and short-term and long-term projection models. Pinniped food habits studies provide indicators of regional changes in prey abundance and distribution and allow calculations of prey size. Collectively these metrics can be used by fishery managers to assess potential overlap with commercial fisheries. BASIS and NBS ecosystem survey data also provide insights into early marine life stages of western Alaska salmon, which is key for understanding population dynamics and bycatch potential.

M10. Groundfish Stock Structure and Salmon Stock Identification - Continuing - (NCSS Objective 6)

National Standard 3 of the MSA requires that management units represent stocks of fish. Climate change is shifting the spatial distribution and migration corridors for several species in the EBS. Members of AFSC's Genetics Research Program (GRP) assess the genetic stock composition of selected groundfish and salmon stocks, including those encountered in new areas (e.g., in the EBS; Spies et al. 2020) and stocks incidentally captured during commercial fisheries (e.g., salmon bycatch, Guthrie et al. 2020) to comply with NS3 and NS8.

M11. Inshore and Coastal Assessments - New - (NCSS Objective 6)

Nearshore habitats are essential to the functioning of marine ecosystems and Alaska communities dependent on living marine resources. Climate change is altering the nearshore marine environment and accelerating the pace of coastal erosion, which determines the ability of these habitats to support living marine resources. AFSC conducts opportunistic assessments inshore of the RACE GAP/SAP bottom trawl survey area when possible in the EBS, which identify and quantify Essential Fish Habitat (EFH) and species responses to habitat change, including shifts in habitat-related distribution and abundance of fishes and crabs using survey data, environmental data, and habitat mapping.

M12. eDNA (Northward Shifts) - New - (NCSS Objective 7)

Environmental DNA (eDNA) analysis facilitates the collection of data on presence/absence and potentially relative abundance of species across the full marine community, from plankton to whales. This approach is ideally suited to detect range shifts and other community changes in the EBS because it is easy to deploy and provides high-resolution data for a moderate cost. In 2021-2022, AFSC is piloting eDNA on the northern Bering Sea survey, Distributed Biological Observatory (DBO) sites, and the Alaska Department of Fish and Game (ADF&G) nearshore Bering Sea Survey in the southeastern Bering Sea, primarily targeting gadids. These collections represent an important starting point, but eDNA data will become much more valuable as a time series is built that can help to identify both seasonal and annual trends in marine communities.

Key Gaps for Monitoring KGM

KGM 1. Discretionary Funds for Rapid / Emergency (< 1 year) Surveys (NCSS Objectives 6 and 7)

Rapid response efforts facilitate the ability to triage sudden shifts in oceanographic conditions and measure ecosystem response. Rapid response, in the form of immediate surveys and field investigations, provides near real-time data to inform forecast models which provide immediate feedback on the repercussions of observed ecosystem changes and provides the NPFMC with early warnings of potential topics of concern. Managers and stakeholders have an opportunity to develop dynamic management strategies that change in response to fluctuating ecosystem conditions.

KGM 2. Supplemental Support for Southeastern Bering Sea Ecosystem Assessment and Monitoring Surveys (NCSS Objectives 6 and 7)

Research goals are to identify and quantify the major ecosystem processes in the southeastern Bering Sea (in the spring and fall) that regulate recruitment strength of key groundfish species. Process and retrospective studies are core tools for identifying mechanisms of change,

developing and testing conceptual and forecasting models, and for identifying functional responses linking distribution, abundance, growth and phenology of fish. The survey components of this research include biennial seasonal surveys of the southeastern Bering Sea for groundfish larvae, age-0, and age-1 groundfish as well as other biotic and abiotic variables (e.g., bottom temperature, zooplankton) that are used in stock assessments, Ecosystem and Socioeconomic Profiles, and the Ecosystem Status Report.

KGM 3. Supplemental Support for Northern Bering Sea Ecosystem Assessment and Monitoring Surveys (NCSS Objective 7)

The annual late summer NBS surface trawl survey provides stock-specific abundance estimates of juvenile Chinook salmon and projections for adult returns to the Yukon River, with abundance models for chum salmon in development. Oceanographic and zooplankton data, as well as observations of fish diets, energetics, and isotopes obtained from the survey and subsequent laboratory analyses are used to evaluate trends in the trophic ecology and condition of juvenile salmon, gadids, and forage fishes in the NBS and their responses to climate change. In addition to providing annual data on juvenile fish abundance, distribution, and nutritional status, the survey supports sampling for multiple research efforts including RPA projects, HABs, and planned development of benthic sampling to assess benthic-pelagic coupling, and water sampling for eDNA projects.

KGM 4. Forage Fish Population Dynamics (NCSS Objective 7)

Research is needed on forage fishes (juvenile gadids, capelin, herring) to better monitor climate-mediated changes in population dynamics, and to understand how links and energy transfer processes between the lower trophic level (plankton) and the upper trophic level (piscivorous fishes) are affected by climate variability. This project will improve acoustic-trawl estimation of forage fish abundance, distribution, and species identification techniques. These goals would be addressed through expansion of survey footprints, modification of sampling methods, and/or improved analytic approaches such as broadband signal processing.

KGM 5. Expand Marine Mammal Assessments - (NCSS Objectives 3, 6 and 7)

Marine mammal surveys of ice-associated seals and all cetaceans are needed to track the implications of climate change on protected species. Bearded, ringed, spotted, and ribbon seals, and all cetaceans have only been surveyed sporadically, and not since 2013. Regular monitoring is needed to assess abundance and trends, especially for the species that are traditional resources for Indigenous communities. Passive acoustics instruments on moorings provide an important time series informing the latitudinal bounds of cetacean distributions. There has been no funding for dedicated surveys of cetacean abundance and trends since 2013. Surveys for cetacean abundance and trends are rare. They can occur biennially or less frequently and in alternating

areas. Other long-term projects monitor multiple indicators of pinniped demography, health and condition, and prey use.

KGM 6. Fully Support NOAA Oceanographic Moorings (NCSS Objectives 6 and 7)

The EcoFOCI maintains five long-term ecosystem moorings in the Bering Sea that provide year-round biophysical data (temperature, salinity, fluorescence, and currents at each site and oxygen nitrate, and PAR at selected sites). Four of the moorings are on the 70-m isobath and the other new site is in the rapidly changing ecosystem north of St. Lawrence Island. For over 20 years, these data have provided metrics used to understand the effects of annual climate variation on the EBS. NOAA/OAR covers only part of the funds required to continue these time series. Additional funds would fully support these existing moorings essential for providing valuable data for validating the ROMS/NPZ models and providing indices to management.

KGM 7. Expanded Biophysical Data Collections on NOAA Moorings (NCSS Objectives 6 and 7)

An expansion of ocean and biogeochemical sampling in the Bering Sea and Arctic Ocean is needed to accurately monitor the impacts of climate change on living marine resources in the Bering Sea, including fishes, crab and other key taxa. NOAA's biophysical moorings provide a platform for the collection of a broad suite of observations. New mooring technology provides an opportunity for expanded data collection. These include RISE moorings (biophysical moorings which sink with ice arrival and rise to the surface with ice retreat); pop-up buoys which map the cold pool and sample the under-ice boundary layer; the Prawler which provides real-time water column measurements (temperature, salinity, oxygen, fluorescence); and sediment traps and bag samplers which measure the connectivity between the benthic and pelagic realms of the EBS. Adding eDNA collection capabilities to existing and new mooring instrumentation will provide opportunities for validating eDNA observations and extend the spatial and temporal scope of biological monitoring to provide early indicators of species distribution shifts.

KGM 8. Expanded Biophysical Data Collections on NOAA Uncrewed Surface Vehicles (NCSS Objectives 5, 6 and 7)

Several new technologies were developed and tested during the last 10 years. These autonomous sampling technologies provide expanded opportunities for data collection in the EBS. The Oculus glider provides high resolution oceanographic data. Uncrewed surface vehicles (e.g., saildrones, https://www.saildrone.com/) provide numerous products ranging from air-sea interactions to tracking marine mammals, fish and crab (De Robertis et al. 2019). The AFSC's Marine Mammal Laboratory is developing multi-spectral sensors specific to northern fur seals that can be included in an unmanned aircraft payload to collect rookery images for abundance surveys. In addition, the utilization of machine learning allows the processing of large amounts of data. These technologies augment shipboard measurement in new and cost-effective ways and

provide critical information in a timely manner to decision makers, stakeholders, and scientists. Acoustic sampling of marine mammal species occurrence could be supported in addition to active acoustics in partnership with fisheries. Zooplankton community structure will be studied using new underway imagery combined with artificial intelligence. NOAA will monitor Harmful Algal Blooms (HABs) to improve collaboration with the Ecology and Oceanography of HABs (ECOHAB) program and prepare long-term sampling routine in future years.

KGM 9. Laboratory Infrastructure - Environmental Tolerances, Food Habits and Bioenergetics (NCSS Objectives 5, 6 and 7)

Laboratories located in Juneau, Kodiak, Newport, and Seattle and on research vessels have a wide range of capabilities that help us understand species and ecosystem responses to varying ocean conditions and climate change. Saltwater wet labs support experimental studies to assess direct and indirect effects of temperature and ocean acidification on fish and crab growth, survival, and reproductive output. Experimental results on species-specific thermal preferences, energy allocation and physiological limitations of groundfish and crab species inform bioenergetics, essential fish habitat and species distribution models. Furthermore, insights into food web structure and energy transfer under changing climate regimes are made possible by laboratory techniques such as stable isotope analysis, bomb calorimetry, lipid and fatty acid analysis, DNA metabarcoding, and stomach content analysis of fish, crab, and marine mammals. Fish age estimates are a key data source for stock assessments and efforts are currently underway to evaluate the use of machine-based technology (FT-NIRS) to determine fish age and identify fish species and populations.

The AFSC has monitored food habits of North Pacific groundfish since the early 1980s. This long-term dataset provides insights into changing conditions and ecosystem interactions among commercial species, their predators, and prey. The AFSC Food Habits database currently contains diet data from nearly 400,000 individuals representing 200 distinct predator species. Decreased funding resources have reduced sample collection and processing at a time when improved data collections for core species are required to assess impacts of climate change. Stabilizing funding for this lab and archival database will provide a permanent repository for sample data collected in the field and add value to our long-term ecosystem monitoring and modeling efforts.

KGM 10. Information Trade-offs with Current and Alternative Sample Size and Data Collection Methods. New - (NCSS Objectives 6 and 7)

Statistical analyses and simulation models are being employed to explore the trade-offs associated with reducing the total number of observations on information loss for fishes and crabs. These studies are being conducted in coordination with stock assessors and those invested in ecosystem monitoring. New analysis will explore the trade-offs in information content associated with current and alternative data collection methodology and associated calibration

needs to assure time series continuity. New technologies offer exciting new opportunities for data collection, however, research is needed to evaluate the quality and feasibility of information, obtained with new technologies, for use in stock assessment. In cases where alternative sampling might supplement or replace existing survey platforms calibration studies will be needed to bridge the time series. In the next 3 years, analysts will likely target research on eDNA, drop cameras, acoustic echosounders, alternative trawl types (e.g., beam/otter trawl, commercial trawls), passive and actively powered uncrewed surface vehicles, and acoustic/oceanographic moorings. Validation of the above techniques and development of analysis approaches to integrate data from new technologies with existing data collection mechanisms are needed.

KGM 11. Strengthen Partnerships with Russian Federation to Share Data on Transboundary Stocks (NCSS Objectives 6 and 7)

There is a compelling need to extend our sampling of fishes and crabs to accommodate transboundary stocks that are presently shifting their spatial distribution in response to climate change. For example, vessel calibration studies could be conducted to allow datasets from adjacent regions to be used to inform transboundary shifts in species distributions and their consequences. Efforts to strengthen international cooperation in surveys for fisheries (such as the Russian American Long-Term Census of the Arctic, RUSALCA project) could be considered. Sampling on many of the transboundary stocks in the Bering Sea is ongoing on both sides of the border. However, data sharing is difficult and there are no established ways to share data. It is apparent that data sharing agreements could benefit research and management of the shared stock in both countries. For example, U.S.-Russian cooperation would facilitate stitching together data from adjacent regions to inform transboundary shifts in species distributions and their consequences. It will also help in forecasting future changes in species distribution and help in preparation for future management of stocks migrating north due to climate changes.

KGM 12. Communication, Cooperation and Infrastructure to Increase Efficiency and Comparability of Monitoring data (NCSS Objective 7)

Communication and coordination is in need of further improvement within NOAA across line offices and among divisions and programs. This could be addressed by funding research to identify and implement standardized approaches to processing and dissemination of data (particularly environmental data) and their derived products. This could be in the form of regular meetings or one-time workshops, and it would be greatly helped by allocation of additional staff time devoted to coordination and maintenance of systems that support storage, processing, and dissemination of data and metadata. This effort would ease access to data collected by individual projects which collectively may provide additional context for interpreting observations through consideration of information collected using multiple observation platforms, including those enabled by new technologies. Products derived from this effort would include databases to facilitate efficient integration of ecosystem observations within stock assessments.

Process Research

P1. Recruitment Processes Alliance (RPA) - Continuing - (NCSS Objective 5)

Research is conducted to detect, understand, and respond to climate-mediated processes affecting ecosystem change and fisheries recruitment strength. Research includes fieldwork, laboratory analyses of field sample collections (e.g., feeding, growth, bioenergetics), laboratory studies, and modeling (statistical, bioenergetic, and biophysical). The RPA joins the efforts of three AFSC programs: Recruitment Processes/Eco/FOCI, Ecosystem Monitoring and Assessment, and Recruitment Energetics and Coastal Assessment, and one OAR/PMEL program (EcoFOCI). Data products from the RPA inform other comprehensive efforts including ecosystem modeling, fish stock assessments, ESRs, and ESPs. Recently, loss of sea days and canceled research surveys have significantly impacted the ability of EcoFOCI and the RPA to conduct ecosystem work.

P2. Ocean Acidification Research - Continuing - (NCSS Objective 5)

Laboratories in Newport, Oregon, and Kodiak, Alaska, support research on survival, growth, and physiology of commercially important fish and shellfish species in response to changes in ocean chemistry. Laboratory experiments on Pacific cod, Arctic cod, and yellowfin sole will assess physiological responses to changes in temperature and pH, and examine the cross-generation impacts of ocean acidification. Research on commercial crab species will continue to determine how multiple stressors will alter species response to ocean acidification and assess the mechanisms of physiological response to lower pH and carbonate availability.

Fixed-site ocean carbonate chemistry monitoring includes mooring in the EBS (M2) continuous, real-time monitoring at the Kodiak Fisheries Research Center, and an evolving network of monitoring sites along the Alaska coastline through a collaboration with AFSC, local communities, and shellfish growers. Development of an ocean acidification (OA) forecast through the newly developed carbonate chemistry package for the Bering10K model enabled the development of an OA index for the Bering Sea Ecosystem Status Report and crab ESPs in 2020. Efforts to collect observational data from the Bering Sea to validate model outputs was planned for 2022.

P3. HABs Research - Continuing - (NCSS Objective 4)

The main objective of the ECOHAB project is to develop a model for predicting the wildlife and ecosystem health impacts of harmful algal bloom (HAB) toxins in arctic and subarctic regions under changing environmental conditions. The research approach combines multiple programs and expertise to identify where blooms occur, how much toxin they produce, how the toxins move through the food web, how fish and marine mammals are impacted by the toxins, and how the changing climate is affecting the occurrence, toxicity, and risks of HABs. Preliminary

findings provide evidence for massive and recurrent toxic blooms that are fueled by warming ocean conditions. This collaborative work hinges on extensive environmental sampling via multiple NOAA led research cruises in the RPA programs. Arctic and subarctic regions have unique conservation issues due to critical dependence on subsistence harvests of natural marine resources by many Native and tribal communities. As human populations in arctic regions face warming trends, they are justifiably concerned about changes that can adversely affect their health, livelihood, and the health of the ecosystems on which they depend for food and other needs. This ECOHAB work is the first to quantitatively explore the transfer of HAB toxins within arctic and subarctic food webs across a broad area at high risk of toxicity. The models to be developed will be the first of their kind for the region, representing an important tool to manage resources and to explore future climate scenarios.

P4. Satellite tagging of northern fur seals - Continuing - (NCSS Objectives 5 and 6)

Satellite tagging of northern fur seals from islands with diverging population trends in the Bering Sea continues to yield comparable metrics on changes in foraging locations, distance traveled, and foraging-bout-length. Coupled with condition indices, this information is fundamental to understanding potential changes in demography related to environmental influences. Efforts are also underway to describe the seasonal movement and climate-linked spatio-temporal dynamics of pollock migration using echosounder data collected along the U.S.-Russian boundary in the Bering Sea. Data on Bering Sea pollock migration patterns and their interannual variability would reduce uncertainties in the AFSC stock assessment analysis by providing information on the relative availability of the stock within the U.S. survey area. Migration data from the MACE echosounders and the associated PMEL oceanographic sensors will provide information on pollock responses to climate conditions and be used to predict pollock migration patterns.

P5. Support development of Rapid Response Indicators of ecosystem status - Continuing - (NCSS Objective 6)

Indicators that are developed within days of the conclusion of field work (Rapid Response Indicators, RRIs) provide quantitative, real-time metrics of ecosystem status. RRIs are typically developed in the field as data are being collected and are available within days of the conclusion of field activities for use in forecast and hindcast modeling scenarios. RRIs provide now-casts of the ecosystem across multiple trophic levels, they reveal changes in progress, and they highlight areas of immediate concern. Fast-track communication of these real-time metrics provides managers and stakeholders flexibility in the decision-making process and permits opportunities to be adaptable that are not available using traditional approaches.

P6. Identify biogeochemical thresholds and mechanisms driving ecosystem reorganization (regime shifts) - Continuing - (NCSS Objective 5)

Changes in climate forcing may influence energy flow through the ecosystem. Research is underway to evaluate how potential changes in ecosystem structure and function (e.g., benthic vs. pelagic pathways) will affect resilience to changes in climate. To answer these types of questions, focused efforts to identify ecosystem or species-specific thresholds to climate drivers and to identify mechanisms of regime shift are needed.

P7. Shifting Spatial Distributions - New - (NCSS Objective 6)

Acoustic and satellite telemetry studies are conducted to better understand seasonal movements and climate-driven distribution shifts of fish, crab and marine mammals (Thorson et al. 2021). Ongoing cooperative AFSC-industry research includes tagging red king crab to characterize seasonal and interannual movement and distribution patterns in relation to bottom water temperatures in Bristol Bay. Long-term passive acoustics monitoring, coupled with data from oceanographic buoys, provides information on cetacean seasonal presence and movements relative to both climate and anthropogenic sound. Pacific cod satellite tagging is conducted to assess large-scale seasonal movement patterns of adult cod between winter spawning and summer feeding grounds, which will shed light on climate-driven shifts in cod distribution into the northern Bering Sea. In addition, indicator time series for population center and area occupied estimates are being generated for groundfish and crab stocks that are selected for ESP development.

Efforts are also underway to describe the seasonal movement and climate-linked spatio-temporal dynamics of pollock migration using acoustic echosounder data collected along the U.S.-Russia boundary in the Bering Sea. Data on Bering Sea pollock migration patterns and their interannual variability would reduce uncertainties in the AFSC stock assessment analysis by providing information on the relative availability of the stock within the U.S. survey area and the share of the stock subject to Russian fishing effort. Migration data from the MACE echosounders and the associated PMEL oceanographic sensors will provide information on pollock responses to climate conditions and be used to predict pollock migration patterns.

P8. Biogeochemical Process Modeling - New - (NCSS Objective 4)

The Climate Program Office (CPO) Modeling, Analysis, Predictions and Projections (MAPP) program funded a new research project focused on the role of biogeochemical processes in controlling LMR-relevant properties in an EBS climate-to-fish modeling framework. This project will conduct a biogeochemical model intercomparison for the Bering Sea. This model intercomparison will couple four existing biogeochemical models, all with contrasting but equally justifiable representations of the lower trophic level dynamics of the Bering Sea, to an

identical hydrodynamic model forced with historical atmospheric and lateral ocean boundary conditions.

Key Gaps for Process Studies

KGP 1. Euphausiid Population Dynamics - (NCSS Objectives 5, 6 and 7)

Climate effects on euphausiid dynamics is currently understudied. Directed field and laboratory efforts that focus on how climate variation influences rates of production, euphausiid community composition, and spatial dynamics are critical to informing and increasing the predictive capacity of our ecosystem models. New work is needed to refining at-sea acoustic measurements of the zooplankton community to resolve euphausiids, field studies to characterize climate-mediated changes in euphausiid phenology across all of Alaska's LMEs, and conducting a suite of laboratory studies that examine climate-forced shifts in euphausiid lipid availability.

KGP2. Nearshore Ecosystems and Juvenile Fish Population Dynamics - (NCSS Objective 5)

Changes to ocean chemistry, hydrodynamics, and coastal food webs impact juvenile fish growth and survival; however, these drivers are understudied using traditional oceanographic methods, and are often impacted by boundary conditions and not well constrained in ecosystem models, despite their importance. We will conduct field and lab studies to better understand what processes and bottlenecks are taking place during the early life stage transition from offshore to inshore rearing (or freshwater to nearshore in the case of salmon) for core commercial species.

Management-Oriented Synthesis

MOS 1. Stock Assessment Enterprise - Continuing - (NCSS Objectives 6, 1 and 2)

Scientists with the AFSC’s Status of Stocks and Multispecies Assessment (SSMA), Marine Ecology and Stock Assessment (MESA), and Resource Ecology and Ecosystem Modeling (REEM) programs integrate the fishery-independent and fishery-dependent data into single and multi-species stock assessments and ecosystem assessments for fish, crab, and marine mammals. These assessments are used to provide quantitative advice for management of living marine resources in the EBS. When combined with climate information, these assessments yield insights into the effect of climate on fish, crab, and marine mammal populations.

MOS 2. Multispecies technical interaction model - Continuing - (NCSS Objective 2)

The Council adopted a management approach that incorporates an ecosystem approach to fishery management as its goal. Within this management framework the Council includes protocols that explicitly consider the implications of mixed-stock fisheries relative to single-species management targets (Ono et al. 2018). In addition, the Council imposes several protocols to

address species interactions including: prohibited species caps, ecosystem level caps on total groundfish removals, and catch deterrents for forage species. The multispecies technical interaction modeling effort simulates some of these interacting constraints on future catch and serves as a tool for evaluating the implications of proposed management changes on catch. In the next 3 years, the work plan for this model includes updates to dynamically project future fish responses to climate variability and change, including modeling effects of environmental influences on catch composition. As such this tool is meant to provide the best expectation of future biological reference points used to estimate future catch within the Bering Sea under changing climate conditions. This model is used to inform the multi-model stock projection models used in ACLIM by generating future representative fishing pathways.

MOS 3. Management strategy evaluations (MSEs) -Continuing - (NCSS Objective 2)

Assessment scientists often utilize MSEs to identify harvest control rules that are robust to rapid climate changes. This approach relies heavily on retrospective studies and process-oriented research to identify the mechanisms underlying recruitment variability (see the Recruitment Process Alliance; RPA) or other responses (e.g., shifts in spatial distribution, growth, or phenology) to changing climate conditions. Relationships derived from process and retrospective studies and the associated sampling, measurement and process error allow scientists to inform the response surface of future management actions by projecting the estimated relationship with uncertainty (see Objective 1). Management strategies will be evaluated relative to agreed upon benchmarks for sustainable fisheries management of crab and fish stocks within an ecosystem context.

MOS 4. Alaska Integrated Ecosystem Assessments and Ecosystem Status Reports - Continuing - (NCSS Objective 6)

The AFSC annually produces Ecosystem Status Reports (ESRs) for the eastern Bering Sea, Aleutian Islands, and Gulf of Alaska for the Council, the scientific community, and the public (Siddon 2020). The ESRs summarize information about the ecosystems and support Ecosystem-Based Fisheries Management in Alaska. Each ESR includes ecosystem report cards, a synthetic ecosystem assessment, and detailed ecosystem status indicators. First developed in 1995, the ESRs have a long history as a vehicle for presenting current ecosystem status to the Council. The annual review by the Council influences each subsequent iteration of the ESRs, creating adaptive products that can be flexible as issues and scientific knowledge develop.

The integrated ecosystem assessment (IEA) program builds on the ESRs to synthesize ecosystem information, including climate impacts, on multiple marine sectors including fishing. IEAs provide a framework for incorporating indicator-based ecosystem assessments, risk assessments, and management strategy evaluations. Amongst other things, the Alaska IEA program provides support for modelling efforts to project short- and long-term effects of climate impacts on fish

and fisheries in the southeastern Bering Sea and to assess the cumulative impacts and risk of long-term climate change on the Bering Sea ecosystem and dependent human communities.

MOS 5. Ecosystem and Socioeconomic Profiles (ESPs) - New - (NCSS Objective 5)

AFSC has a 50-year long legacy of qualitative reviews, field and laboratory process studies, conceptual modeling, and retrospective studies that have focused on detecting mechanisms underlying ecosystem responses to improve stock assessments. NOAA's Fisheries and the Environment (FATE), Integrated Ecosystem Assessment (IEA) Programs and NPRB's Integrated Ecosystem Research Programs (IERP) provided research opportunities to bridge the ecosystem and stock assessment disciplines. AFSC has built up the capacity for including additional pieces of information through major advances in ecosystem modeling, but a communication gap remained between these research advances and uptake within the stock assessment process. The ecosystem and socioeconomic profile, or ESP, builds on this 50-year legacy of mechanistic research for stock assessment by providing a standardized framework that facilitates the integration of ecosystem and socioeconomic information within the stock assessment process and acts as a pathway for use in management advice. The ESP process was initiated in 2014 through the Alaska groundfish Plan Teams and the first formal ESP report appeared as an appendix in the Alaska sablefish stock assessment and fishery evaluation (SAFE) report in 2017. In the last EBS- and GOA-RAPs, we discussed the initiation and formal development of the ESPs for the groundfish and crab stocks in Alaska. As of 2020, we have six ESPs (four groundfish, two crab stocks). We will continue to create new and update current ESPs over the next 3 years and are currently implementing an indicator submission system for ESPs that is linked to the stock assessment cycle for both groundfish and crab stocks.

MOS 6. Risk Tables - New - (NCSS Objectives 1, 5 and 6)

Risk tables are sections within AFSC groundfish and crab stock assessments that summarize factors that may influence a stock's true Acceptable Biological Catch (ABC), but that are not addressed within the stock assessment model and therefore not accounted for in the model-estimated maximum ABC (Dorn and Zador 2020). Factors are categorized as related to the assessment model, the stock's population dynamics, ecosystem conditions, and fisheries performance. Ecosystem Status Reports (ESRs) and Ecosystem and Socioeconomic Profiles (ESPs) are used primarily to inform the ecosystem conditions factors, but also population dynamics and fisheries performance. Risk tables were introduced as a pilot project in five groundfish assessments in 2018. Since 2019 they have been included in all full assessments. Risk tables for groundfish will continue to be refined based on guidance from the SSC and Plan Teams. Pilot risk tables are planned for two crab stocks in 2021.

MOS 7. Species Distribution Models for Identifying Essential Fish Habitat - New - (NCSS Objective 5)

Species distribution models (SDMs) of essential fish habitat (EFH) have been used to describe and map the habitat-related distribution, density or abundance, and vital rates of groundfish and crab in the Bering Sea and other Alaska regions as is required by EFH regulations for life stages of species in fishery management plans. SDMs of EFH were first developed in 2017. New SDMs are in development, where significant advances in methods and data will result in the first comprehensive set of EFH density or abundance maps and a smaller set of vital rate maps incorporating SDM and vital rates for the first time. In addition to supporting EFH mandates, new stock-specific habitat information has been extended to stock assessments through the development of ESPs and to other ecosystem-based fisheries management (EBFM) information needs for our region. For example, efforts will focus on projecting SDMs using Global Climate Models in the Bering Sea to inform species distribution shifts with a changing environment, and including SDMs in individual-based biophysical models to study population connectivity and recruitment informed by spawning locations and spawning stock biomass in other regions over time. Moving to a more temporally dynamic definition of EFH for our regions is prudent given recent and rapid changes in the environment and species distributions. Dynamic SDMs are currently in development for species in the Bering Sea, which is an approach that should be extended for this region and others. Looking ahead, SDM and habitat-integrated population-dynamics models can be developed to describe and identify production rates by habitat, which can be extended to inform understanding of the influence of habitat on population dynamics and to evaluate different management strategies under a changing marine environment.

MOS 8. Transition from ROMS to MOM6 - New - (NCSS Objective 4)

RAP 1.0 relied on the Regional Ocean Model System (ROMS or Bering 10K) with biogeochemistry. In RAP 2.0 analysts will begin the transition to the sixth generation of the Modular Ocean Model (MOM6). When completed, this transition would align high-resolution ocean modeling in the Bering Sea with the state-of-the-art ocean modeling system developed by NOAA's Geophysical Fluid Dynamics Laboratory (GFDL). MOM6 coupled physical/biological models will be used to downscale global climate change to the ecology of subarctic regions, and to explore the bottom-up and top-down effects of that change on the spatial structure of subarctic ecosystems; for example, the relative dominance of large versus small zooplankton in relation to ice cover. Initial start-up funds from OAR for the Climate, Ecosystem and Fisheries Initiative (CEFI).

The ROMS/MOM6 ocean models are core to ACLIM-Phase 2 and Bering Seasons Phase 2 programs (see below). Historically, funding to improve and develop these models was funded through temporary funds from NMFS and the Climate Program Office. It is anticipated that the Climate, Ecosystems, and Fisheries Initiative will provide substantial support for this modeling effort. Existing temporary funding is facilitating the addition of an ocean acidification

component (and nitrogen, carbon cycles, etc.) in collaboration with chemical oceanographers from PMEL and the University of Washington, and their role will increase as this model is developed.

MOS 9. Bering Seasons Phase 2 Program - New - (NCSS Objective 4)

This project is jointly funded by MAPP and the Integrated Ecosystem Assessment (IEA) program. It extends the existing short-term forecasting effort developed in RAP 1.0. In the Bering Seasons Phase 2 program, environmental indices will be derived from the ROMS/MOM6 ocean models to provide information streams for ecosystem-linked assessments and short-term forecasts. The multivariate statistical approach that was tested and published during RAP 1.0 (Hermann et al. 2019) will be used to extract the emergent properties of a coupled physical/biological hindcast (ROMS-NPZ) of the Bering Sea for years 1970–present based on National Centers for Environmental Prediction Climate Forecast System (NCEP CFS) atmospheric hindcast conditions, which includes multiple episodes of warming and cooling (e.g. the cooling of 2005–2009). Further, near-term persistence forecasts of the Bering Sea cold pool and other ocean properties (3-6 months ahead depending on starting month) are produced twice per year and delivered to stock assessment scientists, the Council through the Bering Sea ESR, and the general public.

MOS 10. ACLIM-Phase 2 - New - (NCSS Objectives 1- 4)

In 2020, NOAA's Climate Program Office funded the Alaska Climate Integrated Modeling (ACLIM) Project Phase 2: Building Pathways to Resilience, Through Evaluation of Climate Impacts, Risk, and Adaptation Responses of Marine Ecosystems, Fisheries, and Coastal Communities in the Bering Sea, Alaska. ACLIM-Phase 2 continues and extends the previously funded ACLIM fisheries and climate program to understand and project climate impacts on fish stocks and fisheries to inform sustainable fisheries management in the EBS. The project is a pilot for the CEFI Decision Support Systems (DSS). Investigators are evaluating a range of management and fisher responses to the confluence of rapid ecosystem changes (e.g., marine heat waves and shifting eco-regions) and emerging long-term warming and biogeochemical shifts (e.g., ocean acidification). ACLIM-Phase 2 is one of four national pilot programs that serve as demonstration projects for the CEFI. These demonstration projects are directly responsive to the imperative need for climate informed advice on management tradeoffs that is equitable, sustainable, and adaptive. The objective of ACLIM-Phase 2 is to promote climate-resilient fisheries and coastal communities in the Bering Sea region through integrated climate-informed decision making and ecosystem-based fisheries management. The 3-year integrated research program extends the scientific foundation for sustainable and climate-informed fisheries management of groundfish and crab fisheries of the EBS through evaluation of an ensemble of models under climate change and management scenarios. The multidisciplinary team of ACLIM-Phase 2 builds on the existing capability for regionally-focused, integrated climate, ecological,

and socioeconomic research and modeling (Hollowed et al. 2020, Holsman et al. 2020). ACLIM-Phase 2 will evaluate the effects of, and tradeoffs in, adaptation to support NMFS mandates under the MSA, MMPA, and Endangered Species acts for managed resources in the EBS. ACLIM Phase 2 will 1) expand the current modeling suite developed for the southeastern Bering Sea (SEBS) to the Northern EBS (NBS) where multiple stocks have recently redistributed by coupling spatial distribution (e.g., VAST, delta generalized additive models, empirical orthogonal functions) and food web tools to biological models; 2) expand the suite of key species selected for management strategy evaluations to include other species important for commercial and subsistence harvest; 3) expand socioeconomic models and couple them to ecosystem and stock projection models, and where possible provide community-level projections of changes; 4) expand the regional model hindcasts and projections to include high-resolution ocean acidification (OA) and O_2 dynamics for biological models, and improved spatial nesting of physics and biogeochemistry; and 5) support regular Council, community, and stakeholder scenario workshops in coordination with the Bering Sea Fisheries Ecosystem Plan to support climate-resilient decision making and tradeoff evaluations. Specific project components include a) high-resolution regional ocean modeling; b) biophysical model verification; c) ecological, food web, and marine mammal modeling; d) economic models; e) community engagement; and f) ensemble modeling. It is anticipated that the Climate, Ecosystems, and Fisheries Initiative will provide substantial support for this modeling effort.

MOS 11. Northern Fur Seal Foraging Model in ACLIM-Phase 2 - New - (NCSS Objectives 2 and 5)

One objective of the ACLIM Phase 2 project is to include northern fur seals in the ACLIM multi-model climate and management evaluation suite. This research effort will build on a 3-year foraging model development project that was supported by the Lenfest Ocean program (ending in 2021) that leveraged ACLIM- phase 1 products (hindcasts and CMIP5 projections) to develop and link a bioenergetic model for northern fur seals with current AFSC multispecies stock assessment (CEATTLE) and ecosystem models. The project's bioenergetic modeling effort to date has indicated the importance of including northern fur seals in AFSC's suite of climate change, stock assessment, and ecosystem models; however, spatial consumption efforts are static, limited to lactating females, and operate under the assumption that fur seal distribution will remain unchanged from the current distribution. As a result, efforts within the northern fur seal Lenfest study and newly funded support from COCA/ACLIM2, aim to better understand and predict fur seal behavioral and reproductive responses to shifting prey fields. Within the Lenfest study a stochastic dynamic programming model was built to 1) investigate the optimal behavioral choices of female northern fur seals during lactation under different prey availability and distribution scenarios; and 2) to determine how these scenarios affected reproductive parameters. We also explored how behavioral, physiological, and morphological adaptations present within the otariid lineage affected behavioral choices and reproductive parameters, with

the intent of understanding how these theoretical adaptations might allow fur seals to cope with a changing environment.

MOS 12. Fisheries Integrated Modeling System - New - (NCSS Objectives 1 and 2)

In 2021, NMFS launched the FIMS project. The FIMS project seeks to develop a next generation modeling platform for the efficient implementation of fish and crab stock assessments. This effort draws on a community of practice across NMFS' science centers. Options for ecosystem-linked assessments are included in this research effort. When implemented, the FIMS modeling system will provide an effective platform for the production and delivery of ecosystem linked assessments and management strategy evaluations.

MOS 13. Council Bering Sea Fishery Ecosystem Plan (FEP) Climate Change Taskforce - New - (NCSS Objectives 2 and 3)

The work plan for the Climate Change Task Force of the Bering Sea FEP was approved in December 2020. The work plan outlines a process to 1) collate information on climate change impacts on fish, shellfish, and fisheries in the Bering Sea and potential adaptation options; 2) synthesize existing information in to key impacts, risks, and adaptation options; and 3) communicate the synthesized information to the Council in the form of dynamic tables of impacts and adaptation responses and a biannual Bering sea fisheries Climate change impacts and adaptation report. The latter will include a synthesis of the current state of climate readiness and current climate change information in the Council process.

MOS 14. Council Bering Sea FEP Local Knowledge Traditional Knowledge and Subsistence Taskforce - New - (NCSS Objectives 2, 3, and 6)

In 2019, the Council authorized the implementation of the Local Knowledge Traditional Knowledge and Subsistence (LKTKS) taskforce under the Bering Sea Fishery Ecosystem Plan. The plan formalized an ecosystem-based management (EMB) approach to Bering Sea fisheries, recognizing the critical importance of local knowledge and Traditional Knowledge in better understanding ecosystem processes. The 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 Taskforce's main purpose is to create a protocol on how to access and use LK, TK, and subsistence information in existing management processes and institutional frameworks. We propose the AFSC continues to work with the taskforce in bridging multiple knowledge systems to inform management, and support resilience pathways within the region.

MOS 15. Climate Change and Crab Working Group - New - (NCSS Objectives 1 and 5)

The goal of this working group is to increase cooperation and collaboration among AFSC programs, other researchers, and fisheries stakeholders to improve understanding of climate change impacts on Bering Sea crab fisheries. Working group products will include a collaborative workshop on climate change and adaptation, development of time-varying management reference points, cooperative research with Fisheries and Oceans Canada (DFO) to elucidate shared climate forcing, and development of effective ecosystem indicators for inclusion in crab Ecosystem and Socioeconomic Profiles.

MOS 16. International coordination (e.g., NMFS/DFO, PICES) - New - (NCSS Objectives 2, 4 and 5)

The connectivity of the Bering Sea and Northern Bering Sea across international boundaries necessitates continued engagement, dialog, and cooperation with international partners. International scientific organizations such as PICES and ICES and bilateral partnerships such as Norway-U.S., Korea-U.S., Japan-U.S., and Canada-U.S. remain a key part of progress on climate science research in high-latitude systems. Joint international activities include cross-regional comparisons and climate and ecosystem model collaborations.

MOS 17. The PICES/ICES Working Group on Impacts of Warming on Growth Rates and Fisheries Yields (WGGRAFY) - New - (NCSS Objectives 5 and 1)

This 3-year project from 2020 to 2023 is an international working group that will evaluate the empirical evidence of the temperature-size rule (TSR) for fish stocks (i.e., increased temperatures would result in faster juvenile growth but smaller adult body size). WGGRAFY is a multi-national research effort with four main scientific Terms of Reference (ToRs): 1) assess the capacity of statistical models to incorporate temperature-dependent growth; 2) analyze long-term growth patterns across multiple large marine ecosystems that are experiencing different trends in temperature (including the EBS and Gulf of Alaska); 3) assess the impacts of warming on past yield per recruit of commercial fisheries, and forecast trends in future yield; and 4) identify options expanding scientific community access to global length at age data.

MOS 18. Sustainability of Marine Ecosystems through global knowledge networks (SMARTNET) - New - (NCSS Objectives 4 and 5)

The International Council for the Exploration of the Sea (ICES) and the North Pacific Marine Science Organization (PICES) have partnered to develop an approved project for the United Nations Decade on Ocean Science and Sustainable Development (UNDOS). SMARTNET will establish a global knowledge network (GKN) for ocean science by strengthening and expanding the collaboration of ICES/PICES and partner organizations. It will support and leverage ICES/PICES member countries' activities related to UNDOS, by emphasizing areas of mutual

research interest including climate change, fisheries and ecosystem-based management, social, ecological and environmental dynamics of marine systems, coastal communities and human dimensions, and communication and capacity development. It also incorporates strategies to facilitate UNDOS cross-cutting inclusivity themes relating to gender equality, early career engagement, and involvement of indigenous communities and developing nations in the planning and implementation of joint activities.

Key Gaps for Management Oriented Synthesis

KGMOS 1. CEFI Funding for Fisheries and Climate Decision Support Systems (DSS). (NCSS Objectives 1-5)

The CEFI is a multi-component system designed, in part, to provide infrastructure needed for climate-informed decision making. This includes supplementing existing modeling teams within NOAA laboratories and maintaining the high-performance computing infrastructure as well as ample storage for archived completed model runs. Sustained delivery of climate-informed advice for the NPFMC and fishery-dependent communities depends on permanent funding of the CEFI. The CEFI inter-agency coordinated network of research products serves as the foundation for the delivery of ocean forecasts and projections (Objective 4), evaluation of climate adaptation strategies (Objective 3), climate-ready harvest strategies (Objective 2) and climate-informed reference points (Objective 1).

KGMOS 2. Improve communication of risks of climate change to fishing dependent communities (NCSS Objective 3)

This includes the Council and other fisheries managers (e.g., where management will have to adapt as climate impacts to LMRs occur or are predicted), and other stakeholder groups. Communication products include informational interactive websites, glossy brochures (i.e., ESR "In Briefs") and other products that disseminate the impacts of climate change on LMRs and the expected follow on impact to LMR users.

Other ongoing communications efforts will include implementation of the AFSC Communications Protocol to provide timely information regarding survey operations to coastal and Alaska Native communities; promotion of published papers and Center reports to provide the latest research findings, communications via local papers, radio and television; and 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). As appropriate, we will also use NMFS communications platforms to highlight collaborative efforts (website, Facebook, and other social media platforms regionally and nationally).

KGMOS 3 AFSC Climate Research and Activity Facilitator (NCSS Objective 7)

The AFSC's expanded focus on climate research has created a large administrative burden for the scientific leaders in this research area at the Center. There are a variety of new scientific challenges that require more focus time from scientists at the core of interdisciplinary climate research. By design and reality, ACLIM and the climate science efforts at the Center are not a single program or division, but a crosscutting effort that draws on the scientific skills and experience of all divisions of the Center. This project would create a position (possibly a rotational assignment) that would facilitate this cross-divisional research and improve the scientific output of the Center. This position would be a scientific administrative and coordination role that would support ACLIM, GOA-CLIM, the CEFI, and related initiatives. Primary responsibilities would be organizing meetings, reporting, project and budget tracking, and environmental data integration as needed, and communications.

KGMOS 4 Bridging Knowledge to Inform Bering Sea Management (BKIBS) (NCSS Objective 3)

The Bering Sea (BS) region is undergoing rapid and unprecedented ecological and social changes which require 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 BS 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 BS. The BKIBS project brings together Alaska Native TK holders, scientists, educators, and fisheries managers to develop Indigenous Conceptual Models (ICMs) of the BS ecosystem using an interdisciplinary methodology, framework, and team. This project directly supports Action Module 4 in the Bering Sea Fishery Ecosystem Plan (BSFEP), as well as other ecosystem modeling, climate change, and management projects: 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 BKIBS team underscores a commitment to collaboration with ongoing BS modeling work and North Pacific Marine Fisheries Council research priorities. BKIBS ICMs will interface with ecosystem models, contribute understanding of the changing BS ecosystem, support co-productive work, and inform management decisions. This project has three objectives: 1) Promote interdisciplinary partnerships among TK holders, scientists, and fisheries managers; 2) Develop ICMs for the BS ecosystem based on TK and rooted in interdisciplinary methods; and 3) Document the collaborative methods used to bridge knowledge systems to inform fisheries management, outreach, and educational objectives. A deeply collaborative process grounded in TK will improve management plans through robust inclusion

of multiple ecosystems processes while creating better working relationships among Indigenous communities, Council and NMFS.

KGMOS 5. Invest in training, education, and infrastructure through implementation of CEFI DST. (NCSS Objectives 1 - 7)

There is an overall paucity of scientists who are trained in interdisciplinary science that bridges meteorology, oceanography, fisheries oceanography, social sciences, and fisheries management. There also is a need to improve transparency through public access to data and outreach. New technology can provide improved access to data resources using web-based data server support. Public access to fisheries and research data for the Bering Sea region has been increasing through data portals such as the NOAA Fisheries Open Data Portal (Socrata.com) and data management applications such as through the Alaska Fisheries Information Network (AKFIN). Training and education opportunities have included supporting internships and employment for college students and recent graduates through the NOAA Pathways program, student volunteers, and NOAA scientists in the classroom.

Marine Mammals

The systematic assessments of marine mammals (see Monitoring) is a key component to interpreting potential climate-influenced changes to their populations within the Bering Sea and ultimately to the economies and communities affected by these changes. This can be in the form of common prey targets via commercial fisheries or subsistence use by Alaska Natives. Fishery managers rely on population time series to manage threatened and endangered marine mammal stocks for recovery and to set target goals for commercial fisheries within critical habitat. In addition to abundance trend data; basic life history information on vital rates, health and condition, and seasonal distribution are necessary to understand the mechanisms that may be directly regulating population status. Existing research foci within the eastern Bering Sea are addressing these topics but require reliable support to establish stock assessments of all marine mammal species in the area.

M 1. Northern Fur seal research - Continuing - (NCSS Objectives 2, 5 and 6)

Northern fur seal populations in the Bering Sea have been monitored for over a century. Recent trend data indicates that the largest population of breeding seals at St. Paul Island has declined to the lowest levels in over 100 years. Current funding to support biennial surveys of the Pribilof Islands population and nearby Bogoslof Island in the Aleutian chain is inconsistent. A changing climate and environmental perturbations (e.g., volcanic eruptions) may be having a direct and measurable effect on population abundance and distribution. The mechanisms for this are not clear but under investigation but evidence is emerging that increased prey availability would enhance conditions for greater pup survival and recruitment. Studies involving demography,

satellite telemetry, autonomous surveys of prey, and oceanographic conditions, and bioenergetic and ecosystem models are all required to understand potential threats to fur seal recovery.

Key Gaps for Marine Mammals

KGMM 1. Arctic Marine Assessment Program for Protected Species (NCSS Objectives 6 and 7)

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. A new program, the Arctic Marine Assessment Program for Protected Species (ArMAPPS), is proposed and, if implemented, will include rotating assessment surveys and long-term tracking of populations.

KGMM 2. Modernize Alaska marine mammal assessment surveys (NCSS Objectives 5 and 6)

Investments in research, equipment, and personnel with new types of expertise are needed to modernize marine mammal assessments in Alaska. Gaps include the need for artificial intelligence to streamline processing for image and acoustics data in order to provide data products to managers on a timeline relevant for management decisions and the use of new types of platforms, such as uncrewed vehicles and satellites, to assess marine mammals. While progress has been made on these issues, primarily using temporary funds from NMFS or from OAR, full transition to operations requires additional support. Staff with new types of expertise, such as data scientists and programmers are needed to provide a technical interface between data collection and the new advanced tools used by the agency. In addition, continual investments in equipment, such as new uncrewed systems and passive acoustics recorders, are needed because existing equipment is dated and needs to be replaced on a rotating cycle or risk failure during deployment and subsequent loss of data.

Socioeconomics

S1. Assess economic and social impacts of climate change - Continuing - (NCSS Objective 3)

Modeling of the climate effects on fisheries and the related economic and social impacts with the focused goal of facilitating informed ecosystem-based fisheries management (EBFM) will continue. One significant development since the RAP is that NMFS has developed the Socioeconomic Strategic Plan, Human Integrated Ecosystem-Based Fishery Management (https://www.fisheries.noaa.gov/human-integrated-ecosystem-based-fishery-management-research-strategy-2021-2025-executive-summary), which makes coupling economics and social science research and data collection with climate change and other interdisciplinary research a priority for NOAA.

S2. Modeling fisher behavior in response to changing climate, markets, and management - Continuing - (NCSS Objective 3)

The current ecosystem approach to fisheries management adopted by the Council is far more complicated than the collective suite of single-species control rules and system-level caps. This complex suite of management strategies includes catch share programs, marine spatial and temporal regulations, fishery cooperatives with independent management tools, and incentives to comply with bycatch controls and other constraints. The ACLIM 2.0 project is designed to evaluate how these provisions will perform under changing species compositions, shifting spatial distributions, and changing vital rates and phenology of target and non-target species. A key element of this study will be to model fisher behavior as well as fish responses to climate change. ACLIM 1.0 developed a model that examined how the Council has historically set total allowable catches (TACs) in response to changes in ABC and what share of the TACs were caught by different fisheries given those TACs. ACLIM 2.0 will utilize a wide range of fisher location choice models (e.g., Haynie and Layton 2010), models that evaluate fishery responses to changes in environmental changes (e.g., Haynie and Pfeiffer 2013, Watson and Haynie 2018), and multispecies models that simulate how fisheries interact under changing climate conditions and alternative harvest strategies.

Participation restrictions in catch share programs may limit fishers' abilities to target different species (or fish in different locations) when climate change affects fish and crab populations. Typically, these programs have some limits on trading shares and participation. Fishing companies may be faced with difficult financial choices when they have allocations for a population that is declining or facing increased uncertainty due to climate change. One goal of the RAP is to provide long-term predictions to industry to support informed business decisions. Another goal is to assess the value of providing additional flexibility in future regulations to enable better adaptation in the face of climate change and its effects on fish and crab populations. Research has shown that changing regulations (e.g., catch shares) have a significant impact on how vessels are able to target different species in multispecies fisheries (Abbott et al. 2015, Reimer et al. 2016). Additional work is required to understand the limits of this fishery selectivity and how catch shares and incentive programs can best contribute to achieving management goals.

S3. Identify human community dependence on LMRs and effects of climate change - Continuing - (NCSS Objective 3)

A set of social and fisheries engagement indices were developed using data for human communities throughout Alaska in an attempt to better understand how dependent individual communities are on LMRs, how those communities may be differentially affected by changes in resource management and other external perturbations, and how well each community may be able to adapt to such impacts. In addition, work has been done to develop similar indices focusing on how much communities may be affected by the physical effects of climate change

(e.g., sea level rise, melting permafrost, changes in sea-ice distribution). Combined, these indices are intended to be used to better understand the overall impact that climate change might be expected to have on communities across a broad spectrum, both geographically and socioeconomically. These indices will ultimately be linked to the climate vulnerability assessment for the southeastern Bering Sea. This work can be tied to models of fisher behavior to translate changes in fish populations to fleets to communities.

S4. Regional economic impacts of climate change- Continuing - (NCSS Objective 3)

Past work on regional economic impacts of climate change includes Seung and Ianelli (2016, 2019) which uses a computable general equilibrium (CGE) model to investigate the temporal economic impacts of changes in eastern Bering Sea pollock harvest caused by warming sea surface water. A future study can continue this type of work based on a newly assembled 10 region multi-regional social accounting matrix (10MRSAM) database.

S5. Arctic Council, AMAP, impacts on coastal communities - Continuing - (NCSS Objective 3)

The Arctic Monitoring and Assessment Programme (AMAP) of the Arctic Council wrote a report entitled, Adaptation Actions for a Changing Arctic (AACA) at the request of the Arctic Council. The AFSC is developing Chapter 6 of AACA on the impacts of development in the Bering/Chukchi/Beaufort area, which focuses on the consequences of environmental, economic, and cultural/social changes on people in the Arctic at present and as may be anticipated in the next 10-30 years. The orientation of this chapter is on the consequences of such changes for the people of the Arctic. Loss of sea-ice is projected to increase both the number and volume of ship-based oil spills. The acute and cumulative impacts of increasing rate of introduction of hydrocarbons into the coastal environment is expected to threaten food security of subsistence cultures and it may also lead to the disintegration of subsistence dependent coastal communities based on case studies now in the literature.

S6. Integrated economic impact assessments of ocean acidification - Continuing - (NCSS Objectives 5 and 3)

Research focuses on commercially important fish and shellfish species and coldwater corals. The AFSC conducts ocean acidification studies on king, snow and Tanner crab, coldwater corals, pollock, Pacific cod, and northern rock sole. These experiments are conducted in Kodiak, Alaska, and Newport, Oregon, where species-specific culture facilities and experience are available. Bioeconomic models for Alaska's red king crab, snow crab, and Tanner crab fisheries are being used to forecast fishery performance for a range of climate and ocean acidification scenarios. A bioeconomic model was developed for an Alaska king crab fishery, and combined with a CGE model to compute the temporal economic impacts on Alaska economy (Seung et al. 2015). A bioeconomic model was recently completed to forecast effects of climate change and ocean acidification on northern rock sole (Punt et al. 2021). Ocean acidification (OA) conditions

are being monitored by instruments on moorings in the eastern Bering Sea (M2 and M8). Biological and economic impacts of ocean acidification on Pacific cod will be assessed by forecasting long-term effects of OA on abundance, yields, and fishery income, by applying results from exposure experiments and ocean monitoring/modeling to infer population-scale changes in juvenile growth and survival. The specific objectives are to develop two bioeconomic models for Pacific (i.e., Alaska) cod, one for the eastern Bering Sea, and the other for the Gulf of Alaska, which will be based on age-structured population dynamics for each area, and a pre-recruit function that accounts for long-term effects of OA, which will vary due to oceanographic conditions for each area. The cod bioeconomic models will include effects of OA estimated from cod exposure experiments (Hurst et al. 2019). Results from ongoing experiments will estimate effects of changes in water temperature and pH on cod. Additional funding will be needed to incorporate the estimated effects of changes in ocean temperature into the cod bioeconomic models.

S7. Community and economic surveys - Continuing - (NCSS Objective 3)

Socioeconomic surveys of communities over time provide insight into the economic and social importance of commercial, recreational, and subsistence fisheries in each of the communities. Climate change interacts with significant management changes such as protected areas and catch shares, so ongoing monitoring of the economic and social status of fisheries and fishery-dependent communities is essential to predict the impacts of environmental change and potential future management actions.

S8. Modeling the management and fishery response to changing fish abundance with the ACLIM ATTACH Model - New - (NCSS Objective 3)

A key component in projecting future catch for managed groundfish species in the Bering Sea is translating projected changes in future stock abundance and distribution from ACLIM integrated models into realistic harvest predictions. There are two interconnected components to this process that is conducted in the 'ABC To TAC and Commercial Harvest' (ATTACH) model. First, the Council chooses TACs under the suite of allowable biological catches (ABCs) that result from the stock assessment modeling process; these TACs are constrained by the Bering Sea and Aleutian Islands (BSAI) 2 million metric ton optimum yield limit / ecosystem cap. Second, vessels catch a species-specific share of the Council-determined TACs, typically catching more than 95% of the TACs in aggregate, although there is considerable variation across species. This modeling process is essential, because the nature of fishing in the Bering Sea is such that the catch of each species is a function of the TACs of other species, the creation of catch share programs, bycatch regulations, and other factors. This model can be coupled with socioeconomic scenarios to explore different possible future catch scenarios (Holsman et al. 2020, Reum et al. 2020, Whitehouse et al. 2020) and will be coupled with a range of additional socioeconomic scenarios in ACLIM 2.0.

S9. Developing socioeconomic scenarios to evaluate possible future management and harvest scenarios - New - (NCSS Objectives 1 and 3)

Managing the ecosystem and fisheries of the North Pacific is a complex and dynamic process. The Council and its primary committees meet formally five times a year to address new management issues and to adapt the current system to new scientific information and changing management objectives. Connected to management strategy evaluations (MSEs) is effort of AFSC scientists and Council staff to work with scientists across disciplines and diverse fishery and community stakeholders to develop a set of scenarios that can be coupled with ACLIM 2.0 climate-ocean-ecosystem models to explore what management actions are likely to be most resilient to future climate change.

S10. Identifying fishing effort by modeling Vessel Monitoring System (VMS) and Automatic Information System (AIS) data - New - (NCSS Objective 5)

Many vessels in the United States and Russian North Pacific transmit VMS and AIS data streams that can be modeled to estimate where, when, and for how long fishing effort occurs. AFSC researchers are currently working to estimate recent increases in fishing effort of pollock and Pacific cod vessels in Russia that may impact Bering Sea stocks. This will allow us to better understand whether climate-related shifts of these stocks northward may significantly change the Russian catch of these important stocks and thus require management adjustments by the Council.

S11. Annual Community Engagement and Participation Overview (ACEPO) - New - (NCSS Objective 3)

The Annual Community Engagement and Participation Overview (ACEPO) is an annual report focusing on sustained participation of those fishing communities substantially engaged in the commercial fishery management plan (FMP) groundfish and crab fisheries in Alaska. ACEPO is a community level analysis guided by the Council's management objectives and MSA National Standard 8 (NS8). To understand the different ways that communities engage with FMP groundfish and crab fisheries, the analysis included U.S. communities based on geographic location and, historical and current fishing involvement in Alaska's groundfish and crab fisheries. Four performance metrics of fisheries participation were evaluated: commercial processing engagement; commercial harvesting engagement; the processing regional quotient (measuring the percentage of all FMP groundfish and crab landings occurring in each community); and the harvesting regional quotient (measuring the percentage of all FMP groundfish and crab landings revenue attributable to vessels owned by residents of each community). These indicators provide a quantitative measure of how community participation in Alaska fisheries and how their participation has changed from 2008 through 2019. ACEPO provides a means to measure how future climate change may impact Alaska fishing communities.

S12. Communications Foundation for Co-Producing Science with Bering Sea Communities - New - NCSS Objective 3)

To develop the Bering Sea Climate Regional Action Plan for 2025-2030, over the coming years, the AFSC plans to take steps to strengthen existing relationships and continue to expand reciprocal relationships with Alaska Native communities and fishing communities in the Bering Sea. These relationships can act as a foundation to support collaborative research efforts with AFSC scientists, indigenous scholars, and community members. To execute its mission to manage fisheries and conserve marine mammals, NMFS identifies and prioritizes research that includes climate-driven change in the environment and effects on living marine resources. However, not all communities have had equal access during the process of identifying, prioritizing, or executing regionally specific research needs.

To address these inequalities, NMFS will expand opportunities to advance Environmental Justice in its research through consistent and sustained engagement and collaboration with Alaska Native communities to collaborate with and co-produce marine research to better inform management of living marine resources. This effort will directly support a variety of U.S. government priorities.

AFSC's new Tribal Research Coordinator will assist by providing information about the AFSC research mission and helping to advance a two-way dialogue to strengthen working relationships and build partnerships between researchers and Alaska subsistence hunters, fishers and community members. The goals are to promote information sharing, support each other's individual data collection efforts, develop collaborative research projects, and identify mutual priorities to co-produce research. The Tribal Research Coordinator will also help Regional Action Plan (RAP) team members to coordinate meetings to help implement this RAP and lay a foundation for the 2025 RAP over the next several years. Initial focus will be on the northern Bering Sea, where loss of sea ice shifting fish stocks and changing environmental conditions is profoundly affecting Alaska Native communities. We plan to coordinate closely with the Nome-based NOAA Sea Grant Marine Advisory Program agent and Alaska Native organizations in the region to broaden awareness of this effort.

Key Gaps for Socioeconomics

KGS 1. Expand research to understand how climate change will impact fishery-dependent human communities and evaluate socioeconomic scope for adaptation. (NCSS Objective 3)

Funding is currently limited and only sporadically available through temporary funds and research proposals. There is a need to expand research to assess how changes in the distribution of target and prohibited species (e.g., salmon and halibut) might impact future fishery catches, how changes in value might help offset climate-driven changes in fish and crab harvest, and how alternative management structures may differentially impact different fisheries and human

communities. This project seeks to understand the implications of social-ecological change and the emerging adaptation pathways for BS communities. Marine resources are critical to rural and Alaska Native communities for food security, social cohesion, economic livelihood, and cultural continuity. Reduced sea ice and shifting climate patterns affect food security, well-being, and resilience through the increased risk for both commercial and subsistence fisheries, marine safety hazards such as oil spills, increased marine traffic, severe storm events, and increased tourism on small isolated communities. Collaborative and inclusive research focusing on social vulnerability, adaptation, and resilience is critical to support AFSC's mission to provide the best available science for informed ecosystem-based decision-making. This research works to build enduring relationships with TK holders, Indigenous communities, and non-indigenous issue experts to better understand social-ecological processes and support effective and robust future collaborations. The aims of the research are two-fold: 1) detect and monitor the effects of social-ecological change on BS communities, with particular focus on food security; and 2) develop and facilitate a BS knowledge network.

KGS 2. Adapting to Life Without Ice: Food security, subsistence, and nutrition in the Bering Strait (NCSS Objective 3)

This proposal seeks to better understand the dietary and social implications of diminished sea ice and the emerging adaptation pathways for communities substantially dependent on subsistence resources (e.g., crab, salmon and halibut) in the Bering Strait. It is hypothesized that loss of sea ice will drive changes in subsistence harvest, resulting in dietary and nutritional changes (IPCC, 2019). Documenting recent and historical subsistence practice will address questions about food security and nutrition within rural communities. Examining how community members perceive ecological changes and the lack of sea ice informs possible adaptation pathways and decision-making processes under conditions of rapid change. Preliminary research on St. Lawrence Island (SLI) in 2018-2019 suggests subsistence practice has shifted in recent years to accommodate uncertainty associated with loss of sea ice. Community members report new pinniped and fish species in the region, changes in the timing and abundance of subsistence foods, new migration patterns, sick or wounded animals, and unstable ice conditions which present higher risks when hunting. These observations echo oceanographic and satellite data. Building from the SLI research, this collaborative research will examine material and cultural changes in subsistence diets throughout the Bering Strait region due to loss of sea ice. Focusing on the Bering Strait, subsistence and dietary data will be collected and analyzed within the historical frame to capture shifts in harvest and consumption. The research will contribute detailed information on observed changes and social adaptations to reduced sea ice through the lens of daily subsistence practice. Project findings will inform future management plans and create better working relationships among rural and indigenous communities, the Council, and NMFS.

KGS 3. Non-market values of the Bering Sea Ecosystem (NCSS Objective 3)

Previous research on the non-market values of Steller sea lions (SSLs) has demonstrated that residents throughout the Nation place a large value on reducing threats to endangered species such as SSLs (Lew et al., 2010, Wallmo and Lew 2011). Because there are no market values for much of the value derived by Americans from protecting endangered marine mammals, sea birds, and the ecosystem as a whole, carefully designed surveys are required to estimate the benefits that people experience from a healthy ecosystem. More research is needed to understand the values and priorities from different degrees of environmental protection, especially in the face of a changing environment.

KGS 4. Ecosystem Service Valuation - SPURF (NCSS Objective 3)

The Fish, Food, and Fun: Exploring the nexus of Subsistence, Personal Use, and Recreational Fisheries in Alaska (hereafter the SPURF) project aims to understand the intersection of Alaska subsistence, personal use, and marine recreational fisheries in fulfilling household food needs. SPURF will contribute to an improved understanding of the economic and social values of non-commercial Alaska fisheries, information that is critically important for fishery managers to understand when evaluating fisheries management changes and potential adaptive responses to climate-related changes in fish stocks. The project involves collaborative work with the Alaska Department of Fish and Game (ADF&G) and International Pacific Halibut Commission (IPHC). This scoping project involves activities that will set the stage for a project that will collect and analyze the data necessary to understand issues related to the economic, social, and cultural values of subsistence, personal use, and recreational fisheries (SPURFs), their interrelationships, and the role they play in food security of coastal Alaskans. Project activities include 1) analyzing existing data on halibut subsistence fishing from in coastal Alaska communities to better understand the extent to which it helps meet the halibut needs of households participating in this fishery, trends in participation over time, and differentiated access between Tribal and rural participants; conducting a cross-disciplinary workshop in coordination with ADF&G and IPHC; and 2) conducting a literature review of the economics of subsistence harvesting and food security issues in Alaska.

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