4. Bering Sea Regional Action Plan

4.1 Introduction

The Bering Sea Regional Action Plan (RAP) was published in 2016 (Sigler et al., 2016) and was developed to increase the production, delivery, and use of climate-related information required to fulfill the NOAA Fisheries mission in the regions. The Bering Sea RAP identifies priority needs and specific actions to implement the NOAA Fisheries Climate Science Strategy[14] in the respective regions over a three to five year time period. The Bering Sea RAP focuses on the southeastern Bering Sea, a region that supports large marine mammal and bird populations and some of the most profitable and sustainable commercial fisheries in the United States.

The eastern Bering Sea (EBS) supports some of the most valuable commercial fisheries in the world. Large numbers of seabirds and marine mammals also are found here and subsistence harvests are a critical resource for coastal communities. Evidence reveals that climate-related changes in ocean and coastal ecosystems are already impacting the fish, seabirds, and marine mammals in the region as well as the people, businesses, and communities that depend on these living marine resources. Demand for actionable information on how, why, and when climate change will impact this region is growing.

The Bering Sea Regional Action Plan highlighted more than 30 projects focused on climate science that were active in the region at the time (Figure 4.1, Table 4.1).

[14] https://www.fisheries.noaa.gov/national/climate/noaa-fisheries-climate-science-strategy

Figure 4.1. Summary of 2017 climate linked research from the Bering Sea RAP. Asterisks indicate projects that would be supported if additional funding was available as of 2017. The remaining projects were expected to be supported if funding remained at the 2017 level.

Table 4.1. List of projects and web-links for key climate related research programs noted in the 2017 Bering Sea Regional Action Plan. Note: weblink URLs are listed in footnotes on subsequent pages of the chapter.

Project	Web-Link	NCSS Objective
NPFMC Bering Sea Ecosystem Plan	FEP	Objective 2
Alaska Climate Integrated Modeling Project (ACLIM)	ACLIM	Objectives 1-4
Climate vulnerability assessment for the SE Bering Sea	EBS VA	Objective 4
Belmont Forum Project	RAC Arctic	Objective 2
Recruitment Processes Alliance (RPA)	EcoFOCI	Objectives 5-7
Loss of Sea Ice Research	LOSI	Objective 6
Ocean acidification research	OA AFSC	Objective 5

Project	Web-Link	NCSS Objective
Lenfest research on Northern fur seals	Lenfest Fur Seals	Objective 5
Assessments of economic and human community impacts	Community Profiles	Objectives 4-6
Alaska Integrated Ecosystem Assessments and Alaska Ecosystem Status Reports	Alaska IEA and ESR	Objective 6
Standard Ecosystem Monitoring		Objective 7

This document provides a five year synthesis of the progress that has occurred since the publication of the Bering Sea Regional Action Plan. The document is structured to inform the reader of NOAA's progress towards the goals and objectives of the NCSS. It is structured around each of the NCSS objectives (1-7 in reverse order).

4.2 Activities and Progress

Build and Maintain Infrastructure (Objective 7)

Goals
Build and maintain the science infrastructure needed to fulfill NOAA Fisheries mandates under changing climate conditions.

- Maintain existing surveys and stock assessment infrastructure
- Maintain process oriented surveys
- Maintain existing laboratory infrastructure
- Maintain predator prey research infrastructure
- Maintain existing ecosystem modeling capability
- Maintain existing assessments of economic impacts (e.g., economic SAFE)
- Maintain existing community profiles[15]
- Maintain international research partnerships
- Build and maintain critical research partnerships
- Communicate climate risks
- Training, education, and outreach
- Invest in modeling

Activities
During the period 2015 to present, the AFSC has continued to support the fishery dependent and fishery independent field operations necessary to fulfill its mandates under changing climate conditions in the Bering Sea.

[15] Alaska fishing community profiles website - https://archive.fisheries.noaa.gov/afsc/REFM/Socioeconomics/Projects/communities/profiles.php

NMFS's commitment to the collection, and use, of in-season fishery dependent data to manage catch is a central pillar of the region's sustainable fisheries approach. In the last five years the fishery observer program implemented a fully randomized sampling program (Cahalan and Faunce, 2020) and electronic monitoring. These improvements to data collection continue to provide the infrastructure needed to detect and understand the climate impacts on fish, shellfish and fisheries.

Fishery independent monitoring also provides critical on-going observations. Standard long-line, acoustic-trawl (e.g., Honkalehto et al., 2018) and bottom trawl surveys (e.g., Lauth et al., 2019) were conducted to assess the distribution, condition, age or size composition, and abundance of EBS groundfish, crab, and euphausiids. Ecosystem surveys were conducted to assess and monitor the condition, distribution, and density (as measured by catch per unit effort [CPUE]) of larval and juvenile groundfish and salmon and the species composition, distribution, and density of phytoplankton and zooplankton. In 2014 and 2018, the eastern Bering Sea slope survey was not conducted (Figure 4.2). In 2017, the AFSC initiated bottom trawl surveys of the Northern Bering Sea (NBS) shelf region as part of the Loss of Sea Ice (LOSI[16]) funded research plan. Sampling in the NBS covered 198,858 km^2 of the Bering Sea shelf area in addition to the standard sampling of the EBS area of 492,897 km^2. The timing of this addition was fortuitous because the region had experienced a marine heatwave in 2015/16 and an unprecedented low sea ice year in the winter of 2017/18 (Walsh et al., 2017; Stabeno and Bell, 2019). Results of this survey revealed a spatial shift in the distribution of Pacific cod. This spatial shift persisted in 2018 and 2019 (Stevenson and Lauth, 2019). The bottom trawl survey sampling included substantial analysis of groundfish food habits (stomach collections) and fish condition data, and ecosystem-level impacts of the distributional shift on productivity and food web structure are being quantified.

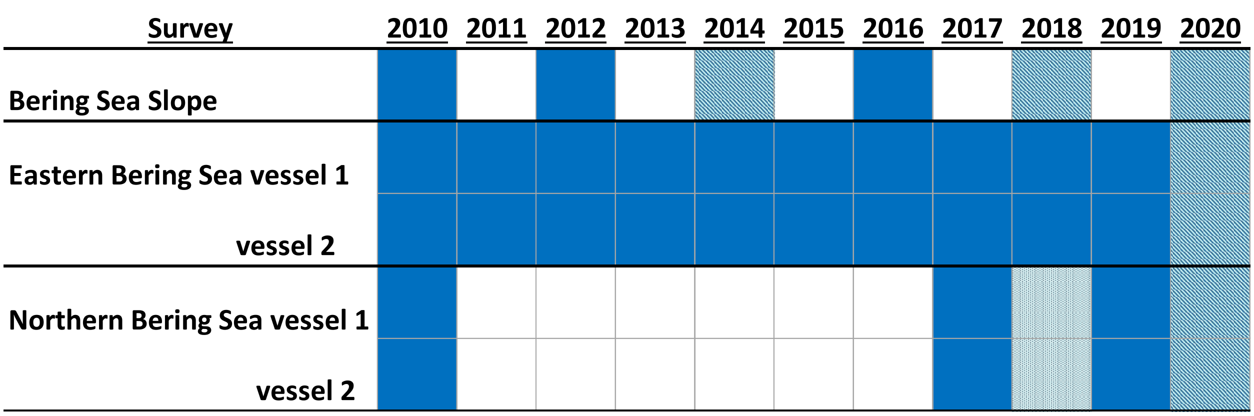

Figure 4.2. Summary of completed (solid), partial (dotted) and cancelled (diagonal lines) Alaska Fishery Science Center bottom trawl surveys 2010-2020. All 2020 cruises canceled due to COVID-19 restrictions.

[16] Loss of Sea Ice Research website - https://www.fisheries.noaa.gov/alaska/ecosystems/habitat-and-ecological-processes-research-regarding-loss-sea-ice

Through the long standing research partnership between AFSC and the Pacific Marine Environmental Laboratory (PMEL, EcoFOCI[17]), seasonal fisheries oceanographic surveys were conducted over the eastern Bering Sea shelf. These surveys collect physical oceanographic measurements as well as data on phytoplankton, zooplankton, and larval fish. Time series data indicate changes in timing of the spring phytoplankton bloom, increases in abundances of warm-affinity larval fish species, and declines in abundances of cold-affinity copepod species. In addition, the Bering Arctic Subarctic Integrative Survey (BASIS[18]) has been conducted annually in the NBS and biennially (even years) in the southeastern Bering Sea shelf. This survey deploys a surface trawl and mid-water acoustics targeting juvenile salmon and pollock. They also provide indices for phytoplankton and zooplankton biomass and species assemblages. Time trends in the total stations sampled during BASIS surveys show a decline in recent years (Figure 4.3).

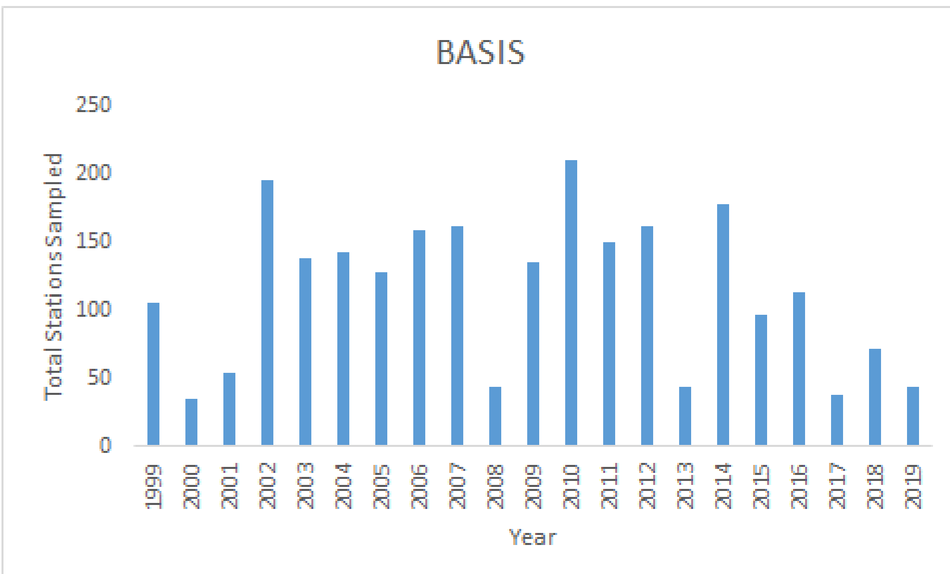

Figure 4.3. Total stations sampled by year during the BASIS (southern and northern Bering Sea combined) surveys. Sampling occurs annually in the NBS and biennially (even years) in the SBS. In 2015, external funds were provided to sample some stations in the SBS during 2015.

Laboratory capabilities including food habits, genetics, assessments of thermal tolerance and vulnerability to changes in pH, aging, and behavioral ecology were maintained, however some were reliant on unpredictable funding.

Progress summary

Advanced technologies were used to collect information from remote locations. For example, deep-sea circulation in the Bering Sea was evaluated using Argo Data (Johnson and Stabeno, 2017). Ice dependent seals were monitored using unmanned aerial surveys (Angliss et al., 2018). An exciting new development was the advancement of uncrewed surface vehicles

[17] EcoFOCI program website - https://www.ecofoci.noaa.gov/
[18] Website for the BASIS survey - https://www.fisheries.noaa.gov/alaska/population-assessments/bering-arctic-and-subarctic-integrated-survey

(USVs, developed by Saildrone™) for use in collecting oceanographic (Mordy et al., 2017) and fish backscatter (De Robertis et al., 2019) data. Transformative aging methods have been introduced that hold the potential for rapidly aging groundfish (Helser et al., 2018). Data from these platforms enhance and improve the Alaska Fisheries Science Center's (AFSC) ability to monitor changes in ocean conditions and the responses of fish and shellfish to these changes.

With the exception of the slope regions of the eastern Bering Sea, NOAA has met its goal of maintaining and expanding its climate science infrastructure through the use of base funding and external grants. In recent years, the Bering Sea RAP had to supplement funding for moorings in the Bering Sea. Likewise, advancements in new technologies were heavily leveraged by external grants. The critical need for ecosystem moorings in the Bering Sea has been demonstrated by the high number of citations that utilize information from these moorings. Finding a mechanism to ensure funding for PMEL moorings is a high priority in the future. Evidence of the rapid transition from research to operations for USVs is underscored by the deployment of three Saildrones™ in 2020 as a partial replacement for the NMFS standard acoustic-trawl surveys for pollock; an action necessitated by the inability of NOAA to deploy NOAA research vessels during a global pandemic.

Performance relative to reaching these objectives are measured as described below.

- The successful deployment of fishery independent surveys including: post-juvenile fish and shellfish surveys, juvenile fish surveys, and ichthyoplankton/zooplankton surveys with underway oceanographic sampling to provide synoptic understanding of marine mammal, fish, and shellfish responses to environmental change. 100% of existing Bering Sea Shelf surveys were maintained. Coverage of the eastern Bering Sea slope region was missed in 2014 and 2018. Additional surveys were added in the northern Bering Sea in 2017, 2018, and 2019. While the inclusion of surveys of the NBS increased the survey footprint by approximately 40%, coverage of the Bering Sea slope was diminished.
- Deployment of three upward looking moorings with advanced sensors to increase coverage of pollock movement across the US - Russian border.
- The successful deployment of fishery dependent data collections.

Tracking Change (Objective 6)

Goals

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

- Produce Alaska Integrated Ecosystem Assessment and Ecosystem Considerations Chapter (Renamed to Ecosystem Status Report)
- Maintain Standard ecosystem monitoring
- Loss of Sea Ice research
- Coastal assessments
- NOAA Moorings

Activities

In partnership with PMEL, oceanographic monitoring surveys were conducted along the 70 m isobath line and moorings were deployed and maintained (Tabisola et al., 2017; Lomas et al., 2020). These surveys and moorings provided important ecosystem indicators that were reported to the NPFMC as contributions to the Bering Sea Ecosystem Status Report[19] (ESR).

As noted earlier, NOAA has invested in diverse fishery dependent and fishery independent ecosystem monitoring. The AFSC and Alaska Department of Fish and Game) (ADF&G) use this information in population dynamics models in stock assessments to track time trends in recruitment, growth, age composition, reproductive potential, and total biomass. Most of these assessments are age- or size-based and some include ecosystem linkages (Lynch et al., 2018). Ecosystem linkages include temperature effects on catchability, and bottom temperature effects on survey availability (Thorson, 2019; Thorson et al., 2020), temperature effects on growth and consumption (Holsman et al., 2016), and predation impacts on CPUE (Hanselman et al., 2018) or juvenile survival (Spencer et al., 2016). Collectively, these assessments provide the best available scientific information on recent changes in stock status in response to climate variations.

A framework for qualitatively evaluating relationships between time trends in ocean variables and key vital rates used in assessments has been improved through the adoption of Ecosystem and Socio-economic Profiles (ESPs) (Shotwell et al., in prep.). The ESP process was initiated in 2014 and has since gone through a phased development and review through the groundfish and crab Plan Teams and Scientific and Statistical Committee of the North Pacific Fishery Management Council (NPFMC). Starting in 2017, this framework has been used for three high profile groundfish and crab stocks in Alaska, and three additional applications are underway (Fedewa et al., 2019; Shotwell et al., 2017, 2018, 2019a,b). The framework extracts indicators of hypothesized ecosystem linkages that were formally included in the Alaska Marine ESRs. These indicators are evaluated within an applied stock-specific framework using a consistent statistical method to rank and display the evidence in support of hypothesized relationships. While SAFE chapters have included stock-specific ecosystem considerations for several decades, the new framework provides a standard statistical format for evaluating qualitative inferences about climate impacts on fish and fisheries. To date, the main utility of the ESP framework is its contributions to evaluations of qualitative information to inform adjustments to harvest recommendations that are external to stock assessments (Townsend et al., 2019; Dorn and Zador, 2020). However, stock assessment scientists anticipate that ESPs will accelerate the transition from qualitative evaluations to the integration of time-proven relationships into ecosystem-linked assessments in the future. It is anticipated that by monitoring relationships between key indicators and relevant assessment parameters and functional forms, the benefits of including the relationship to inform the assessment can be evaluated.

[19] Bering Sea Ecosystem Status Report website - https://www.fisheries.noaa.gov/alaska/ecosystems/ecosystem-status-reports-gulf-alaska-bering-sea-and-aleutian-islands

Over the last five years, methods for estimating the effects of fishing on essential fish habitat have improved considerably. Key advancements include the update of the catch-in-areas database (Smeltz et al., 2019) and the application of numerous geospatial statistical tools (GAMS, Maxent, and VAST) to identify and detect explanatory variables that include temperature (Pirtle et al., 2019; Brodie et al., 2020; Goldstein et al., 2020; Rooper et al., 2021). Results facilitate tracking of climate impacts on the distribution of suitable spawning and nursery habitats as well as spatial shifts in post-juvenile distributions.

Through various internal and external funding lines, assessments of the impacts of climate change on Alaska communities have advanced (Seung et al., 2015; Seung and Ianelli, 2016). The Economic SAFE document now includes socio-economic profiles that provide a snapshot of time trends in key indicators of fishery dependent community status. In addition, the Groundfish and Crab Economic SAFEs now include a dashboard to quickly assess time trends in key economic indicators (Fissel et al., 2019). While these have not been formally linked to climate drivers, they serve as a starting point for evaluating mechanisms through which climate drivers impact society.

Ecosystem Status Reports are produced annually to compile and summarize information about the status of the Alaska marine ecosystems for the NPFMC, the scientific community, and the public. To advance ecosystem-based management, scientists must take a broader approach in providing scientific advice to resource managers. The ESRs provide the NPFMC with contextual ecosystem information to inform their annual quota-setting process. The Ecosystem Status Reports of the Groundfish SAFE provide the historical perspective of status and trends of ecosystem components and ecosystem-level attributes using an indicator approach. For the purposes of management, this information must be synthesized to provide a coherent view of the ecosystem effects to clearly recommend precautionary thresholds, if any, required to protect ecosystem integrity. The eventual goal of the synthesis is to provide succinct indicators of current ecosystem conditions and a prognosis of how fish stocks are expected to fare, given concurrent information on ecosystem status. To perform this synthesis, a blend of data analysis and modeling is required annually to assess current ecosystem status in the context of historical and future climate conditions. Ecosystem indicators with hypothesized ecosystem linkages to fish vital rates are then utilized within the ESP framework.

Progress summary
Significant improvements to AFSC's ability to track climate related trends in the eastern Bering Sea have been realized over the last five years. These advancements have been accelerated through internal discretionary and external funding. Many lessons were learned from recent marine heat waves. The marine heat waves revealed the importance of reviewing in-year environmental and socio-economic indicators and the establishment of the Preview of Ecosystem and Economic Conditions (PEEC) meeting ensures this will occur. While scientists within the AFSC have a long history of leadership in the exploration of assessment-relevant ecosystem linkages, the co-occurrence of the NCSS, marine heat waves, climate change, and the establishment of a common statistical framework for evaluating these relationships (i.e., ESPs) has focused new attention on these factors.

Performance relative to reaching these objectives is measured as described below.

- The successful deployment of oceanographic moorings with advanced sensors for monitoring physical and biogeochemical change
- The inclusion of satellite-derived indices of sea ice extent, area, and thickness for use in monitoring changes in environmental conditions
- The successful deployment of advanced technologies for use in monitoring physical, biological, and chemical changes in remote regions of the Bering Sea
- Maintenance of time series included in the (ESRs)
- Bering Sea moorings provide useful indicators of ecosystem trends and are reported in the ESR and PEEC meetings
- Ecosystem indicators are now evaluated mid-way through the calendar year as part of the PEEC meeting
- ESPs have been completed for Alaska sablefish, St. Matthew Island blue king crab, and Bristol Bay red king crab. A draft ESP was completed for Eastern Bering Sea Pacific cod
- To date ecosystem indicators have been transitioned into several eastern Bering Sea assessments:
    - EBS pollock added a multispecies assessment as an appendix to the SAFE
    - EBS Pacific cod added bottom temperature-linked VAST model projections as an index to assess survey catchability
    - Bering Sea Aleutian Islands yellowfin sole includes bottom temperature and mean survey start date as a covariate on survey catchability
    - Alaska sablefish adjusts both the survey and fishery indices for whale depredation within the assessment model and in the calculations of acceptable biological catch.

Understanding Mechanisms (Objective 5)

Goals

Identify the mechanisms of climate effects on ecosystems, living marine resources, and resource-dependent human communities.

- Publish results of Bering Sea Project[20]
- Conduct southeastern Bering Sea ecosystem assessment research on recruitment processes to understand production of key groundfish species
- Conduct Ocean Acidification research[21] on commercially important fish and shellfish species and cold-water corals
- Continue northern fur seal research to assess processes underlying recent declines in overall production
- Conduct ice-associated seal surveys to gain insights into how climate affects these populations

[20] Bering Sea Project website - https://www.nprb.org/bering-sea-project/about-the-project/
[21] AFSC Ocean Acidification research website - https://archive.fisheries.noaa.gov/afsc/HEPR/acidification.php

- Continue passive acoustic surveys for whales to gain insights into how climate affects these populations
- Conduct research on seabird bycatch and use of seabirds as ecosystem indicators
- Study economic effects of climate change
- Project social and human community effects of climate change.

Activities
The scientists at the AFSC have a long legacy of leadership in the study of mechanisms underlying the effects of climate variability and change on marine ecosystems and resource-dependent communities. Internal and external funding has been used to conduct numerous process studies that have been the basis for many of the ecosystem indicators tracked by the AFSC. During the last five years, EcoFOCI (https://www.ecofoci.noaa.gov), a cross-Line Office partnership between AFSC and PMEL, continued its mission to conduct process studies that target Bering Sea walleye pollock, phytoplankton, zooplankton, salmon, and flatfish. These process studies have improved our understanding of mechanisms linking climate drivers to larval or juvenile survival (Wilderbuer et al., 2016; Duffy-Anderson et al., 2017; Hertz et al., 2018, Kimmel et al., 2018; Porter and Ciannelli, 2018; Stabeno and Bell, 2019; Yasumiishi et al., 2019; Yeung and Cooper, 2019; Cooper et al., 2020; Farley et al., 2020). In addition, qualitative network models (QNMs) were used to evaluate management interventions intended to promote the rebuilding of a collapsed stock of blue king crab (*Paralithodes platypus*) around the Pribilof Islands (eastern Bering Sea) (Reum et al., 2020a).

The AFSC developed a cross-divisional research team focused on Pacific cod. This team sought to understand the mechanisms underlying the abrupt onset of marine heat waves and the subsequent collapse of the Gulf of Alaska (GOA) cod stock (Barbeaux et al., 2020) and the marked shift in the spatial distribution of EBS cod (Stevenson and Lauth, 2019). The cod working group completed studies of: cod stock structure (Spies et al., 2020), juvenile cod thermal tolerance (Laurel and Rogers, 2020), and cod movement (Nielsen et al., 2020). The record breaking low ice year also provided new insights into ecosystem responses to abrupt climate change (Duffy-Anderson et al., 2019).

Also, during the last five years, the AFSC Resource Assessment and Conservation Engineering (RACE) Program has continued to use laboratory experiments to evaluate the potential effects of ocean acidification (OA) on federally-managed fish and crab species in Alaska. This work, mostly funded through the NOAA Ocean Acidification Program, is aimed at quantifying OA's physiological effects to predict how fisheries and ecosystems will be affected. In general, fish species in Alaska are relatively resistant to OA (Hurst et al., 2016, 2017; but see Hurst et al., 2019), while crab species are relatively sensitive (Long et al., 2016, 2017, 2019; Meseck et al., 2016, Swiney et al., 2016; Coffey et al., 2017), particularly when OA is combined with increased temperature (Swiney et al., 2017). This work is being used to parameterize stock-assessment models to understand the degree to which individual fisheries and Alaskan coastal communities are vulnerable to OA.

The AFSC Midwater Assessment and Conservation Engineering (MACE) Program deployed four bottom-mounted, upward-looking echo sounder moorings located on the U.S./Russia boundary. In addition to collecting active acoustic data, the moorings were equipped with environmental data sensors through a partnership with PMEL. These moorings were deployed in 2019, and were retrieved in 2020. Data from the moorings will be used to evaluate pollock movement across the U.S.-Russia Convention Line and to examine linkages between migratory behavior and environmental data, results which could provide support for climate-enhanced assessment modeling of EBS pollock.

Focused research on mechanisms underlying northern fur seal foraging have been accelerated through several research partnerships between the Alaska Fisheries Science Center, the Alaska Regional Office, the University of Washington, Innovative Technology for Arctic Exploration, Pacific Marine Environmental Laboratory, and the Lenfest Ocean Program[22]. The bulk of these efforts seek to quantify fur seal behavioral and population responses to their prey through bioenergetic modeling, hindcasting, and deploying innovative technologies such as USVs (Kuhn et al., 2020) and back mounted video cameras. The results from these efforts contribute to fur seal models examining behavioral and population responses to simulated prey fields derived from an end-to-end ecosystem model. In addition, this effort has quantified factors affecting northern fur seal energy expenditures, estimated population level prey consumption, and hindcasted walleye pollock consumption by fur seals to begin coupling a fur seal bioenergetic model with AFSC existing ecosystem and multispecies-stock assessment models (McHuron et al., 2019; McHuron et al., 2020).

Several studies of ice dependent seals were conducted during the last five years. Unoccupied aircraft systems (UAS) have been deployed to understand the impact of loss of sea ice on ice associated seals in the remote arctic (Moreland et al., 2015). Impacts of changing patterns of sea ice extent to the body condition on ice dependent seals have also been examined (Boveng et al., 2020).

Passive acoustic monitoring (PAM) for marine mammals (including pinnipeds and cetaceans) has been ongoing in the Bering Sea via long-term subsurface moorings as well as short-term underway sonobuoy deployments. The mooring work has been funded through a variety of external sources and through continued partnership with PMEL for space on the oceanographic moorings as well as ship time to deploy stand-alone PAM moorings in critical locations. The sonobuoys were donated to AFSC by the Navy, and their deployments have occurred on joint PMEL/AFSC cruises as well as on the International Whaling Commission POWER cruises. The primary focus of the research has been on the critically endangered eastern population of North Pacific right whales (which number in the tens of animals). Results include identification of new call types (Crance et al., 2017), and calling behaviors (Crance et al., 2019) that can be used to track this population, as well as new techniques for distinguishing this species from the acoustically similar bowhead whale (Thode et al., 2017). Data collected have also shown that

[22] Lenfest Ocean Program fur seal project website - https://www.lenfestocean.org/en/news-and-publications/cross-currents/2019/northern-fur-seals-in-the-bering-sea-are-declining-researchers-want-to-know-why

this population is now being detected farther north than in earlier years (Wright et al., 2019), as well as in a high traffic Aleutian Pass (Wright et al., 2018). Changes in the timing of many other marine mammal species, particularly in the northern Bering Sea, have been observed and are currently being prepared for publication. Several studies have utilized Bering Sea AFSC passive acoustic recordings to study other marine mammals including: Frouin-Mouy et al. (2019, ribbon seal), Clark et al. (2015, bowhead whales), and Garland et al. (2015, beluga whales).

Progress summary

Ongoing studies of ecosystem processes in the Bering Sea continue to improve our mechanistic understanding of causal linkages between climate variability and change and ecosystem responses. While this understanding can always be improved, these studies provide the mechanistic understanding of several key ecological linkages necessary for the development of short-term forecasts and long-term projections of the Bering Sea ecosystem for use in short term forecasting and long term climate projections.

Performance relative to reaching these objectives is measured as described below.

- Publication of numerous papers linking ecosystem change to processes underlying production of marine species
- Successful deployment of upward looking sonar and passive acoustic devices for monitoring spatial shifts in fish and marine mammals
- Successful deployment of USVs concurrent with deployment of satellite tags on northern fur seals to assess capture efficiency and foraging behavior
- Successful deployment of UMAs to assess ice-associated seals in remote regions.
- Incorporation of proposed mechanisms in qualitative evaluations (ESPs)

Projecting Future Conditions (Objective 4)

Goals

Identify future states of marine, coastal, and freshwater ecosystems, living marine resources, and resource dependent human communities in a changing climate.

- Ocean model projections. Coupled physical/biological models (ROMS-NPZD) are 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
- Incorporate ocean acidification effects into existing ocean models. An ocean acidification module is being added to the coupled physical biological model (ROMS-NPZD)
- Climate-enhanced single-species projection models. Climate-enhanced single-species projection models have been completed for walleye pollock, Pacific cod, arrowtooth flounder, and Bristol Bay red king crab and northern rock sole and provide 20- to 50-year forecasts of their abundance, including a measure of the uncertainty of these forecasts
- Climate vulnerability assessment for the southeastern Bering Sea[23]. A climate vulnerability assessment for the southeastern Bering Sea, which will qualitatively assess

[23] Southeastern Bering Sea climate vulnerability assessment webpage - https://www.fisheries.noaa.gov/data-tools/bering-sea-vulnerability-assessment-species-specific-results

species vulnerabilities to climate change and provide guidance on research prioritization, currently is underway
- Identify human community dependence on LMRs and effects of climate change
- Support Arctic Council and AMAP impacts on coastal communities. The Arctic Monitoring and Assessment Programme (AMAP) of the Arctic Council is preparing a report entitled “Adaptation Actions for a Changing Arctic (AACA)” at the request of the Arctic Council

Activities

Several advancements in seasonal-to-interannual forecasting of the impact of climate variability on marine ecosystems have been realized in the last five years. Through funding provided by the Climate Program Office, seasonal-to-interannual forecasts of Bering Sea ocean temperature and sea ice extent at high spatial and temporal resolutions have been tested with promising results (Jacox et al., 2020) at six month time scales. These coupled ocean-biophysical models have the potential to extend environmental tracking to include hindcasts of phytoplankton and zooplankton bloom timing, distribution, and abundance (Kearney et al., 2020).

In 2015, NOAA funded the Alaska Climate Integrated Modeling project (ACLIM[24], Hollowed et al., 2020). This was a large interdisciplinary, multi-institution, research project that was designed to address long term impacts of climate change on fish, fisheries, and fisheries-dependent communities. The ACLIM framework downscales global climate model projections based on different global greenhouse gas emission scenarios (based on shared socio-economic pathways (SSPs) and representative concentration pathways (RCPs)) to a 10 km resolution, 30 layer coupled regional ocean model that includes carbonate dynamics and nutrient-phytoplankton-zooplankton dynamics (Bering 10k, Hermann et al., 2019; Kearney et al., 2020). Output from the Bering 10k projections of the future of the Bering Sea marine ecosystem are used to drive upper trophic level population dynamic models of various levels of biological complexity including: vulnerability assessments (Spencer et al., 2019), climate enhanced single species models (Spencer et al., 2016), multispecies models (Holsman et al., 2020), food web models (Whitehouse et al., in press), and size spectral models (Reum et al., 2020b). Efforts are underway to include fully coupled end-to-end models this fall.

Progress summary

Considerable progress has been made during the last five years towards objective 4. A substantial 3-year effort to validate short-term (1-9 month) Bering Sea ocean forecasts, using global forecasts from the North American Multi-Model Ensemble to drive a downscaled ocean model of the Bering Sea, is nearing completion. The results will quantify the forecast uncertainty for a range of seasonal starting and end dates. A pilot forecast for summer 2020 Bering Sea bottom temperature was released in April 2020 as part of the Alaska Integrated Ecosystem Assessment Program's PEEC workshop; these results will take on greater importance with the cancellation of bottom trawl surveys in summer 2020. The first operational use of these products (delivery of short-term forecasts to the North Pacific Fisheries Management Council through the Bering Sea ESR and the development of a publicly-accessible

[24] ACLIM website - https://www.fisheries.noaa.gov/alaska/ecosystems/alaska-climate-integrated-modeling-project

website) is scheduled for spring 2021. Further, the use of these short-term ocean forecasts to drive fisheries recruitment models for key species (walleye pollock, Pacific cod, and arrowtooth flounder) is currently being tested.

The recent adoption of the Climate and Fisheries Initiative within NOAA bodes well for the continuation of efforts to conduct and improve climate forecasts and projections.

Performance relative to reaching these objectives is measured as described below.

- Completion of long-term high resolution coupled model projections under multiple emission scenarios
- Completion of long-term projections of future distribution, growth, reproductive potential, and abundance of Bering Sea groundfish and crab
- Incorporation of proposed mechanisms in quantitative models (forecasts and projections)
- Completion of a Bering Sea vulnerability assessment

Informing management (Objectives 1 - 3)

Goals

Identify appropriate, climate-informed reference points for managing LMRs; identify robust strategies for managing LMRs under changing climate conditions; and design adaptive decision processes that can incorporate and respond to changing climate conditions.

- Complete and publish climate-forced single- and multi-species models
- Complete the North Pacific Fishery Management Council, Bering Sea Fishery Ecosystem Plan (FEP)
- Conduct and publish Management Strategy Evaluations (MSEs) to identify harvest control rules that remain effective as climate changes
- Maintain a suite of models designed to provide scenarios of future fish and shellfish production under a variety of climate and fishing scenarios through the Alaska Climate Integrated Project (ACLIM)
- Develop multispecies technical interaction models for use in evaluating management approaches that incorporate an ecosystem approach to fishery management through management of incidental catch and bycatch
- Synthesize information from completed and ongoing regional studies conducted by Japan, the United States, and Norway through the Belmont Forum RAC Arctic project
- Design adaptive decision processes through the development of LK-TK and climate action modules within the FEP

Activities

In accordance with objectives 2 and 3 of the NCSS, the ACLIM modeling suite is being used to design and evaluate the performance of current and alternative management strategies within the context of region-specific projections of anticipated societal responses to changing climate conditions. In Phase 1, the ACLIM project has successfully projected the implications of climate change on the distribution, abundance, and reproductive potential of groundfish and crab and the implications of these changes on fisheries. These projections were used to evaluate the value of EBFM strategies in forestalling climate-induced declines in fish catch (Holsman et al., 2020). Demonstration of an operationalized integrated modeling suite has been achieved through the rapid uptake of updated global climate model output from the Coupled Model Intercomparison Project (CMIP-6) into the ACLIM coupled modeling suite. Through new funding from Coastal Ocean Climate Applications program (COCA), Phase 2 of the ACLIM project will expand this effort to include impacts on marine mammals (northern fur seals) and impacts on fishery-dependent communities.

Objective 1 of the NCSS calls for the identification of climate informed reference points for managing LMRs. In December 2018 the NPFMC approved a Bering Sea Fishery Ecosystem Plan[25] (FEP). The FEP adopted an FEP Climate Module Task Force to provide a conduit for exchanging climate relevant information with fisheries managers. This task force, when coupled with the ACLIM research program, provides a vehicle for developing climate adaptation strategies within an open and inclusive environment, allowing voices from a broad range of stakeholders to be considered in the development of strategic approaches to managing fisheries in a changing climate.

The Belmont Forum RAC Arctic project[26] successfully synthesized the implications of climate change on U.S., Norwegian, and Japanese fish and fisheries. Three synthesis manuscripts are under development for a special theme section in ICES Journal of Marine Sciences (Drinkwater et al., 2021; Mueter et al., 2021; Haynie et al., in prep.).

The NPFMC FEP also established a LK/TK/Subsistence Action Module. This group is exploring protocols for using Local Knowledge (LK) and Traditional Knowledge (TK) in management and understanding impacts of Council decisions on subsistence use. Impacts of actions to adapt to climate change will be explored through ACLIM Phase 2 and will inform the LK/TK/S Action Module.

Progress summary

The NPFMC has adopted an annual Preview of Economic and Ecological Conditions (PEEC) in the early summer prior to the fall evaluation of stock status for groundfish and some crab populations. This preview provides an update on key biological, physical, chemical, and economic indicators that allows early detection of climate driven anomalies. In part, the PEEC meeting was established because early indicators of the implications of the 2015-16 marine heat wave were missed or not fully accounted for by scientists and managers.

Products from the PEEC, the ESR, and the ESPs are used to inform risk tables that document different sources of scientific uncertainty that are external to stock assessments. The short-term forecasts and long-term projections provide the foundation necessary for designing, testing, and implementing climate ready harvest advice. The adoption of the FEP provides a

[25] Bering Sea Fishery Ecosystem Plan website - https://www.npfmc.org/fishery-ecosystem-plan-team/
[26] Belmont Forum Arctic projects website - https://www.belmontforum.org/archives/projects/resilience-and-adaptive-capacity-of-arctic-marine-systems-under-a-changing-climate

forum for inclusive participatory decision making with respect to fisheries management in the future.

Solidifying the funding for the ACLIM modeling suite would provide continuity within the program going forward. Pairing FTEs with continued research opportunities, the approach currently used for the EcoFOCI program and the approach recommended for the Climate and Fisheries Initiative (CFI), is recommended for ACLIM as well.

Performance relative to reaching these objectives is measured as described below.

- Completion of comparative testing of the performance of current and alternative harvest strategies for managing groundfish and crab under a changing climate
- Demonstration of the operationalization of the ACLIM modeling suite
- Establishment of an open forum for discussion of current and alternative management strategies under a changing climate through FEP action modules

4.3 Conclusions

Thoughts on what went well and lessons learned.

The combination of strategically directed opportunity funds that accelerated research, the emergence of abrupt climate events (e.g., marine heatwaves and storms), growing evidence of changing climate on the world's oceans (USGCRP, 2018; Pörtner, 2019) and the recognition of the importance of the ocean in the 17 United Nations Sustainable Development Goals made the NCSS a highly relevant strategic planning document. The NCSS provided much needed guidance and structure for the design and implementation of AFSC's climate science research enterprise. It provided clear goals and objectives that allowed AFSC's interdisciplinary research teams to clearly understand how products of their research would contribute to the larger goals of providing climate informed harvest strategies and climate ready harvest control rules.

The periodic release of large and small funding opportunities worked very well. Small funding opportunities within the RAP regions maintained interest in the program and the supplemental funding leveraged larger projects. The larger funding opportunities allowed NMFS to leap forward in its knowledge and capabilities across all seven strategic goals. In particular, the release of multi-year funding from internal and external funds from programs such as NPCREP, FATE, RTAP, NPRB (including the Bering Sea Project), NFS, Lenfest, and COCA were very valuable. These opportunity funds allowed the development of fully coupled climate to fish and fisheries models for short-term forecasts and longer-term projections of the future productivity of the Bering Sea.

Monthly meetings with RAP teams improved communication and collaboration between NMFS/OAR research teams. Many RAP team members were highly involved in the planning and execution of the 4th Effects of Climate Change on the World's Oceans meeting in 2018. This gathering of scientists from across the world in the U.S., mid-way through the first five years of the NCSS, was very fortuitous as it provided in-person communication of research ideas and products across the regions.

Recognition of the global, national, and regional importance of climate change research contributed to the development of NOAA's Climate and Fisheries Initiative which outlines how NOAA will deliver next-generation high resolution ocean simulations for use across all of NOAA.

Potential considerations for a RAP 2.0

Future focal areas - A particular focus on developing a permanent infrastructure for quantitative forecasting and climate projections should be a key focus of RAP 2.0. Planning for this effort has already started as part of the Climate and Fisheries Initiative which will provide hindcasts, nowcasts, S2D forecasts, and decadal to century scale projections of ocean conditions using state of the art high resolution ocean models (MOM6). Efforts to provide clear on-ramps to inform fisheries management through RAP 2.0 is a clear and tangible goal.

Metrics and milestones to consider - Follow a similar approach used for the annual Progress and Plans reports and spreadsheet in terms of aiming to provide readers (leadership, partners) with pertinent information that highlights what progress has been made and what is left to accomplish.

Table 4.2 highlights some of the key RAP achievements.

Table 4.2. A selection of EBS RAP activities organized by NCSS Objective.

Informing Management (NCSS Obj. 1 – 3) • Adoption by the NPFMC of a Bering Sea Fisheries Ecosystem Plan (FEP) • Evaluation of EBFM strategies in forestalling climate induced declines in catch using the ACLIM framework
Understanding Mechanisms and Projecting Future Conditions (NCSS Obj. 4 & 5) • Validation of short-term Bering Sea ocean forecasts • Development of the ACLIM framework • Climate vulnerability assessment for the southeastern Bering Sea • Conduct ocean acidification research on commercially important species • Conduct process studies on pollock, zooplankton, phytoplankton, salmon, etc.
Infrastructure and Tracking Change (NCSS Obj. 6 & 7) • Maintain research capabilities, including food habits, genetics, behavioral ecology, etc. • Maintain standard ecosystem monitoring • Ecosystems Status Report and IEA • Use of advanced technologies (UxS) to expand survey capability

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Chairs past and present: Mike Sigler (2015-2017) and Anne Hollowed (2018-Present)

Current Members:
PMEL: Phyllis Stabeno and Carol Ladd
AFSC: Janet Duffy-Anderson (fisheries oceanography), Alan Haynie (economics), Jeremy Sterling (marine mammals), Ed Farley (salmon), Kerim Aydin (ecosystems), Kirstin Holsman (ecosystems/bioenergetics), James Thorson (habitat and EFH), Kalei Shotwell (stock assessments and ESPs)

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