Regional Action Plan for Southeastern Bering Sea Climate Science (draft)

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EXECUTIVE SUMMARY

The southeastern Bering Sea 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. Climate-related changes in ocean and coastal ecosystems are already impacting the fish, seabirds, and marine mammals as well as the people, businesses, and communities that depend on them. As a result of the changes already observed, demand for actionable information on how, why and when climate change will impact Alaska is rapidly growing.

The Alaska Fisheries Science Center (AFSC) acquires and distributes the scientific information necessary to fulfill the mission of the National Marine Fisheries Service (NOAA Fisheries or NMFS) to sustain fish, seabirds and marine mammals and their ecosystems for the benefit of the nation. To continue to fulfill the mission in the face of climate change, AFSC seeks to acquire and develop information needed to understand, prepare for, and respond to climate change impacts on fish, crabs, and marine mammals. The ultimate purpose is to use the information to explore and develop science-based strategies for sustaining fisheries, marine mammals, and resource-dependent communities in a changing climate.

The NOAA Fisheries Climate Science Alaska Regional Action Plan (ARAP) explains efforts underway to increase the production, delivery, and use of the climate-related information required to fulfill the NOAA Fisheries mission. As part of the NOAA Fisheries Climate Science Strategy, the ARAP conforms to a nationally consistent blue-print that guides efforts by NOAA Fisheries and partners to address information needs organized into seven science objectives that represent the process of managing the nation’s fisheries in the face of changing conditions. The ARAP identifies strengths, weaknesses, priorities, and actions to implement the Strategy in Alaska over the next 3-5 years, and it contributes to implementation of the Strategy by focusing on building regional capacity and partnerships to address the seven science objectives illustrated by the pyramid figure below.

As illustrated in the seven levels of the pyramid of objectives (above),the ideal elements of managing living marine resources (LMRs) under changing conditions is the same throughout the nation. The seven science objectives generate seven questions that are addressed in the ARAP,.

Questions addressed by the ARAP

1. How can climate-related effects be incorporated into ***LMR reference points***?
2. What are robust ***LMR management strategies*** in the face of climate change?
3. How can climate-related effects be incorporated into ***adaptive LMR management processes***?
4. How will the ***abundance and distribution of LMRs*** and marine ecosystems change in the future, and how will these ***changes affect LMR-dependent communities***?
5. How and why ***does climate change alter LMRs, ecosystems, and LMR-dependent human communities***?
6. What are the observed ***trends in climate, LMRs and LMR-dependent communities***?
7. What ***science infrastructure*** is needed to produce and deliver this information?

(Bold faced numbers in parentheses identify the number of the objective and question to which the preceding text refers.)

In the process NMFS follows to implement the Magnuson-Stevens Act (MSA), scientific observations are made and processed into information (**7**) that can be analyzed (**6, 5, 4, 2**) to produce benchmarks of overfishing and other national standards (**1**) that inform the management (regulatory) processes (**3**). How well each of these elements is attained under the scenario of climate change in the eastern Bering Sea is the subject of this report.

The scientific infrastructure (**7**) needed by AFSC to produce the analyses and deliver the benchmarks is reasonably well developed within AFSC and its NOAA partners (OAR, NESDIS) for the eastern Bering Sea. NMFS AFSC has survey projects in place that are maintaining the long time series of physical and biological observations sufficient to identify independent trends in climate, LMRs and LMR-dependent communities (**6**). Making connections among the trends to identify the mechanisms of climate impacts (**5**) and to develop climate-informed reference points (**1**) is at times made problematic by the mismatch between biological, human dimensions and physical data sets with regard to the times and localities of the observations. The older survey projects were put in place some time before concerns about the impacts of climate change became evident, hence physical survey platforms did not originally incorporate synoptic biology and *vice versa*. As resources permit existing projects are being modified and new projects developed in order to integrate physical and biological observations. For example, the Recruitment Processes Alliance (RPA) combined historically independent survey efforts with field surveys to provide the improved synoptic data sets that are essential to develop climate-informed reference points (**1)**, develop harvest strategies that are robust to climate induced change (**2**), inform models of future conditions (**4**), and to identify climate driven mechanisms of change (**5)**. As our scientific infrastructure (**7**) institutional experience increases and the skill of our models improves, AFSC will be providing climate-informed reference points to the adaptive management processes (**3**) of the North Pacific Fishery Management Council (Council).

NMFS and the Council can take three important steps to improve efforts to identify and adapt to climate change impacts on federally managed fisheries in our region. 1) NMFS needs to be able to inform the Council and industry with about a 10 year lead time, as to which commercially important species are likely to be winners and losers in regard to climate change in Alaska. These forecasts need to incorporate uncertainty. Such forecasts would assist the Council in adjusting management programs (i.e., catch share programs) as necessary, and allow the industry to "tune" their capacity (e.g., number of fishing vessels) to match productivity, 2) NMFS and the Council need to identify and monitor thresholds in ecosystem parameters that signal the need to adjust management strategies, and 3) NMFS needs to continue on-going ship-based surveys to monitor changes in biomass, age-structure, and distribution of commercially important groundfish species in the Bering Sea and Gulf of Alaska.

INTRODUCTION

The effect of annual climate variation has been observed to impact fisheries in Alaska; however the impact of climate change on fisheries is unclear. For example, the ecological effects of reduced sea ice have impacted a major fishery in the southeastern Bering Sea for walleye pollock, but this fishery recovered in subsequent years when sea ice again was more widespread. These climate impacts, while temporary, allow us to understand some of the future impacts of climate change. The NMFS Climate Science Alaska Regional Action Plan (ARAP) explains how NOAA Fisheries works to understand the impact of climate change on fisheries and is part of a national effort by NMFS. This first ARAP will focus on the southeastern Bering Sea Large Marine Ecosystem (LME). The waters of the southeastern Bering Sea support large marine mammal and bird populations and some of the most profitable and sustainable commercial fisheries in the country. Our understanding of climate effects on southeastern Bering Sea fisheries, while incomplete, is greatest among the five LMEs of Alaska. Subsequent Strategies will focus on these other LMEs (Gulf of Alaska, Aleutian Islands, northern Bering and Chukchi seas, Beaufort Sea), if funding allows. The primary customers for this information are the North Pacific Fisheries Management Council (NPFMC) and the NMFS Alaska Regional Office. Climate science by the Alaska Fisheries Science Center is conducted collaboratively with the Pacific Marine Environmental Laboratory.

Our climate science approach is composed of three parts: ecosystem monitoring, process studies, and modeling, retrospective analyses, and management strategy evaluations. The three parts, monitoring, process studies and analyses are the three legs of the stool on which our understanding of climate effects is seated. Ecosystem monitoring consists of standard oceanographic surveys which sample ocean physics, phytoplankton, zooplankton and egg, larvae, and juvenile stages of fish. Process studies are shorter term studies directed toward understanding ecological relationships (e.g., primary production rates, predator-prey relationships). Both the ecosystem monitoring and the process studies typically are supported by laboratory studies (e.g., growth response to temperature) and laboratory analyses (e.g., lipid content of sampled zooplankton and fish). Modeling and retrospective studies provide a framework for jointly understanding the results of the ecosystem monitoring and process studies. Modeling can be complex (ecosystem models that are computationally intensive) or simple (bioenergetics models). All three parts are necessary to meet objectives 5 and 6 of the Strategy. Modeling, as well as management strategy evaluations, are necessary to meet objectives 1 through 5 of the Strategy. The Alaska Fisheries Science Center makes a significant investment (~$9M per year) in ecosystem monitoring, process studies, modeling, retrospective analyses, and management strategy evaluations in order to understand climate effects on fisheries, protected species, and ecosystems. Typically this process work is part climate and part ecosystems, fish, or marine mammals and the climate part is about $5M.

We can project some of the future impacts of different climate change and fishing scenarios. Our goal is to predict winners and losers (fish) within ecosystems that could impact predator/prey relationships of commercially exploited populations. However our ability to project future impacts is limited by our understanding of ecological processes. This understanding is sufficient to project climate change impacts for only 3 of 21 comprehensively assessed Fish Stock Sustainability Index (FSSI) stocks in the southeastern Bering Sea; climate change will probably lead to reduced abundances of walleye pollock (through loss of sea ice) (Mueter et al., 2011) and red king crab (through reduced calcium carbonate) (Long et al., 2013; Punt et al., 2014) and unchanged abundance of northern rock sole (Wilderbuer et al., 2013). For example for walleye pollock in the eastern Bering Sea, data from integrated ecosystem surveys conducted by AFSC (BASIS; citation or website??), provided a mechanistic understanding of the impact of stanzas (continued back to back years) of reduced/increased sea ice in spring on the food web for young of the year gadids (e.g. walleye pollock) via the interchange of lipids (i.e., fats), fish fitness during critical periods of life, and survival to older age classes.

Because quantitative assessments are few (only 3 of 21 FSSI stocks), a qualitative assessment currently is underway for the southeastern Bering Sea. This climate vulnerability assessment will qualitatively assess species vulnerabilities to climate change and also provide guidance on research prioritization. The vulnerability assessment uses expert elicitation methods to quantify a species' exposure and sensitivity to expected climate change. Vulnerability, as used here, refers to a reduction in a species' productivity or abundance associated with an expected change in climate. In addition, an ocean acidification risk assessment (Mathis et al., 2015) was conducted by scientists at the NOAA Pacific Marine Environmental Laboratory and Alaska Fisheries Science Center. This assessment predicted that the intensity, extent and duration of ocean acidification in the coastal areas around Alaska will increase with the highest socio-economic risk accruing to regions in southeast and southwest Alaska that are highly reliant on fishery harvests and have relatively lower incomes and employment alternatives. Lastly, in December 2015, the North Pacific Fisheries Management Council decided to develop a Bering Sea Fisheries Ecosystem Plan. One of the priority action modules of this plan would address climate change.

Climate science information is brought forward to the North Pacific Fisheries Management Council. A primary outlet is the Ecosystem Considerations chapter of the Stock Assessment and Fisheries Evaluation report, which has been produced annually for 20 years. This report includes both ecosystem information as well as climate indicators such as average bottom temperature and krill biomass. The climate and ecosystem information also are applied to explain recruitment variation in individual species, which is available for some species with sufficient research and understanding. The latter information is particularly useful to justify catch quota adjustments for the high-volume, high-value fisheries of the southeastern Bering Sea. The NOAA Fisheries Climate Science Strategy calls for assessment of progress on seven objectives. Efforts are underway (i.e., relatively new), or ongoing (i.e., well-established) for the southeastern Bering Sea, however progress and the rate of progress varies substantially among objectives. For example, implementing the development of decision processes that can incorporate and respond to changing climate conditions (Objective 3) awaits the more precise information and improved tools now being developed under other objectives. The Council has an adaptive management process that has occasionally incorporated climate change information into its decisions in the past on an *ad hoc* basis. Routine incorporation of climate-informed reference points under the formal mathematical criteria of accepted stock assessment models awaits future developments. This Climate Science Strategy will complement a Fisheries Ecosystem Plan currently being developed for the southeastern Bering Sea.

ASSESSMENT

In this section, we assess the status of progress on the seven objectives for the southeastern Bering Sea. An action plan for the next 3-5 years follows in the next section. For each objective, the status of progress is followed by brief descriptions, in bullet form, of specific projects. Initiation or completion of some objectives depends on other work. As noted above, initiating development of an adaptive decision process (Objective 3) depends on making more progress on several other objectives (1, 2, 4 and 5). For further example, the identification of robust management strategies (Objective 2) depends on identification of future states of marine and coastal ecosystems (Objective 4).

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

Status: Underway.

- **Single and multi-species models with climate forcing.** The purpose of this project is to incorporate climate effects into single and multi-species models (Figure 1), which are then used to derive climate-informed reference points. The general approach is: 1) statistically fitting population-dynamics models to historical survey and fishery biomass data in order to estimate recruitment, historical harvest rates, selectivity, and annually varying natural mortality; 2) subsequent fitting of the recruitment estimates from each model to spawning biomass and environmental covariates (e.g., cold-pool area, bottom temperature, cross-shelf transport, zooplankton biomass) from a hindcast of a coupled physical-biological oceanography model (Regional Ocean Modeling System-Nutrient Phytoplankton Zooplankton Detritus model, ROMS-NPZD); 3) use model-selection criteria (AIC) to select the subset of climate indices that best fit each model-specific set of recruitments; and 4) project the model forward in operating mode for each climate scenario to derive recommended harvest rates to meet management objectives under future climate conditions.

Objective 2: Identify robust strategies for managing LMRs under changing climate conditions.
Status: Underway.
The identification of robust strategies depends on identifying future states of marine and coastal systems, as described in Objective 4.

- **NPFMC Fisheries Ecosystem Plan.** A fisheries Ecosystem Plan (FEP) was approved by the Council in December 2015. The FEP includes a climate module that would: 1) synthesize current climate change project outcomes; 2) prioritize species for management strategy evaluation (MSE); and 3) run MSEs on specific species and scenarios identified by the Council. This will take place on a 5-7 year cycle and will be summarized in an eastern Bering Sea Climate Change and Fisheries Assessment Report.
- **Management strategy evaluations (MSEs).** The purpose of this project is to identify harvest control rules that remain effective as 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. These studies inform the response surface and projection using the estimated relationship (see Obj. 1), except in each simulation year of the projection, the harvest strategy for each species in the model is determined from a recommended harvest control rule and "realized harvest" is modeled as a function of fisher behavior, spatial distribution of fish, and economic pressures using socio-economic models. These models track the "true" and "perceived (including sampling/measurement and process error)" of the population, wherein, the harvest control rule is applied to the "perceived"population. The realized harvest is then fed into the starting conditions for the next year of the simulation along with "sampled" survey biomass (e.g., index of biomass with error). Management strategies will be evaluated relative to agreed upon benchmarks for sustainable fisheries management within an ecosystem context.
- **Alaska CLIMate Project (ACLIM).** This project involves a suite of models designed to provide scenarios of future fish production under a variety of climate and fishing scenarios. The project is the U.S. Bering Sea node of the ICES/PICES Strategic Initiative on Climate Change effects on Marine Ecosystems (SICCME). The SICCME effort is coordinating research nodes in China, Japan, Korea, Russia, the California Current, the

Gulf of Alaska, the Pacific Islands, the Barents Sea, Georges Bank/Gulf of Maine, the Gulf of Mexico, the Norwegian Sea, the North Sea, the Baltic and possibly the high Arctic. The goal of ACLIM / SICCME is to provide quantitative scenarios for future distribution and abundance of fish and fisheries by 2019/2020. The ACLIM project is jointly funded by FATE (Fisheries And The Environment), SAAM (Stock Assessment Analytical Methods), and NPCREP (North Pacific Climate Regimes and Ecosystem Productivity).

The ACLIM Bering Sea node features a suite of models that represent a full range of structural complexity ranging from single species and multi-species projection models (see above) to whole ecosystem models (size spectrum and Ecopath with Ecosim) to fully coupled end-to-end models (FEAST) (Figure 2). This range of model complexity provides the analysts with the ability to track different sources of uncertainty in the projection modelling effort. For example the simpler models (single species and multi-species) models allow exploration of the full range of parameter uncertainty for a narrow suite of functional responses, whereas, whole ecosystem models and FEAST provide the ability to track emerging properties of ecosystem structure or spatial temporal patterns of change. The project has two phases.

In phase 1, the multi-model projections will be run to provide a suite of potential fish distributions and fishers responses to a suite of climate change scenarios. The climate change scenarios will include projected climate conditions under 2 Representative Concentration Pathways (RCPs) using at least 3 global climate models from the CMIP5 suite. Output from these climate change scenarios will be used as boundary conditions and downscaled using the regional ocean model noted above. Output from downscaled projected ocean conditions will be used as noted in Objective 1 above to project the future distribution and abundance of fish and fisheries.

In phase 2, the projected scenarios from Phase 1 will be presented to regional fishery management councils, industry and other non-governmental organizations to seek input and advice on the realism of the harvest strategies used in Phase 1. Based on input from Phase 2 discussions, the harvest strategies will be modified and the multi-model projection suite will be run again. The outcome of this two phase effort will be to to identify the most realistic representation of future responses of fishers and fish to changing climate with the expressed goal of identifying strategies that are robust to changing ocean conditions.

- **Multispecies technical interaction model.** The North Pacific Fishery Management Council (NPFMC) adopted a management approach that incorporates an ecosystem approach to fishery management as its goal. Within this management framework the

NPFMC includes protocols that explicitly consider the implications of mixed stock fisheries relative to single species management targets. In addition, the NPFMC 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 modelling effort simulates these interacting constraints on future catch and serves as a tool for evaluating the implications of proposed management changes on catch. The model dynamically projects future fish responses to climate variability and change and estimates future catch within existing or proposed constraints. As such this tool provides 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.

- **Belmont Forum project.** This project will synthesize information from completed and ongoing regional studies conducted by Japan, the USA and Norway to examine how climate impacts in the Subarctic to Arctic transition zone may affect future marine ecosystems of the Pacific and Atlantic Arctic, their resource management, and the socio-economic status of human communities in the regions. Natural and social scientists will meet with stakeholders from the fishing industry, regional management bodies, governments and coastal communities in at least three workshops to assess whether the biological, management and socio-economic systems have the resilience and adaptive capacity to cope with anticipated changes. These workshops will: 1) review and synthesize impacts of climate change on components of Arctic marine ecosystems; 2) compare and contrast the impacts in the Atlantic and Pacific sectors of the Arctic; 3) identify major issues of concern, including biological and socio-economic threats and opportunities, from both biological and socio-economic perspectives; 4) review the ability of current management frameworks to adapt to likely future changes; and 5) assess the resilience and adaptive capacity of fish, fisheries, other living resources, resource-dependent human communities, and resource management institutions to future climate change.

Objective 3: Design adaptive decision processes that can incorporate and respond to changing climate conditions.
Status: A work in progress.
The NPFMC currently has a process that adapts harvest actions to changing measurements from fishery independent surveys. Changes in fishery independent surveys and other direct observations are used to adapt fishing mortality to estimates of biomass for those stocks on which such information is available. What is not well worked out is how and when the North Pacific Fishery Management Council should react to climate-informed reference point changes. Information on changes in the ecosystem, including climate change, for the area of this RAP are

presented annually to the Council. Implementing Objective 3 is an area that needs considerable attention, discussion, and education. This discussion should engage all subsidiary bodies of the North Pacific Fishery Management Council, as well as the Alaska Regional Office. The two phase approach developed by ACLIM to involve the Plan Teams, Scientific and Statistical Committee, and Ecosystem Committee should provide a starting point for these discussions.

These processes are not well worked out because management targets for fishing mortality and spawning biomass are often calculated by assuming stationary population processes, but under climate change this assumption may be violated. Frameworks for incorporating non-stationary responses of exploited populations under the changing influence of the environment are needed. For example, climate-enhanced single- and multi-species assessment models, conditioned on variable trophic and environmental conditions, can be projected to derive climate-specific harvest reference points (Moffitt et al. 2015, Holsman et al. 2015).

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

- **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—for example, the relative dominance of large vs. small zooplankton in relation to ice cover.
- **Derive environmental indices from ocean models.** A multivariate statistical approach is used to extract the emergent properties of a coupled physical/biological hindcast (ROMS-NPZD) of the Bering Sea for years 1970–2009, which includes multiple episodes of warming and cooling (e.g. the recent cooling of 2005–2009), and a multidecadal regional forecast of the coupled models, driven by an IPCC global model forecast of 2010–2040.
- **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. Extensions of these models that include shifting overlap of predators and prey have been tested for the Bering Sea. These projection models, while based on functional relationships, depend on a detailed understanding of ecological processes affecting population productivity and thus benefit from process studies. See objective 1 for more information on the approach of these models.
- **Climate-enhanced multi-species projection models.** The climate enhanced multispecies

statistical catch-at-age model (CEATTLE) estimated population dynamics of walleye pollock, Pacific cod, and Arrowtooth flounder under future climate and trophic conditions. The model uses inputs of temperature and climate indices from downscaled climate hindcasts and projections to produce biological reference points (e.g., $F_{40\%}$) conditioned on future climate scenarios, trophic interactions, and predator harvest rates. See objective 1 for more information on the approach of these models.

- **Climate vulnerability assessment for the southeastern Bering Sea.** A climate vulnerability assessment for the southeastern Bering Sea, which will qualitatively assess species vulnerabilities to climate change and provide guidance on research prioritization, currently is underway. The vulnerability assessment uses expert elicitation methods to quantify a species' exposure and sensitivity to expected climate change. Vulnerability, as used here, refers to a reduction in a species' productivity and or abundance associated with a changing climate, both climate change and multidecadal climate variability. This vulnerability assessment will be expanded in the future as the species vulnerability relates to LMR dependent human community vulnerability.
- **Identify human community dependence on LMRs and effects of climate change.** 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 socio-economically. These indices will ultimately be linked to the climate vulnerability assessment for the southeastern Bering Sea that is described above.
- **Arctic Council, 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. 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. The report is expected to be released during the second half of 2016. 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.

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

- **Bering Sea Project.** The Bering Sea has been the focus of a 40-year history of studies on processes underlying recruitment of walleye pollock, as well as, biological and physical oceanography. The region has been the beneficiary of a suite of integrated interdisciplinary research efforts including Bering FOCI, the Southeast Bering Sea Carrying Capacity Program, and the Inner Front Study. An integrated ecosystem research program recently was completed in the eastern Bering Sea (Bering Sea Project, 2007-2014) (Figure 3). The most comprehensive integrated ecosystem assessment ever conducted was completed, revealing how climate cycles affect the Nation's largest fishery. This research has been continued at a smaller scale and has focused on understanding recruitment processes of important southeastern Bering Sea fish species (Recruitment Processes Alliance).
- **Loss of Sea Ice research.** Northern Bering Sea surveys will enumerate commercially important shelf species such as snow crab, yellowfin sole, and juvenile salmon which have distributions extending beyond the current area of the southeastern Bering Sea surveys. The resulting survey effort will cover most of the eastern Bering Sea shelf and will be repeated biennially.
- **Predator prey food habits studies.** AFSC scientists had the foresight to acknowledge the importance of the collection and analysis of food habits information. This foresight provided one of the world's largest collection and longest time series of food habits of fish and crabs. This time series allows analysts to develop spatial and non-spatial models of predator prey interactions for use in stock assessments and short-term and long-term projection models.
- **Laboratory studies and analyses to understand climate effects on physiology, bioenergetics, and habitat use.** Changes in water temperature and chemistry can directly impact the growth rate and distribution of fish and shellfish in marine environments (Figure 4). Differential thermal preferences can additionally lead to increases or decreases in species overlap and concomitant predator-prey interactions. Laboratory experiments are conducted to parameterize bioenergetic models of fish growth and energetic demand at the core of climate-enhanced models and to understand direct and indirect impacts of changing pH levels on fish and crab species. Laboratory studies and field surveys of fish thermal preferences are conducted to project future species distributions and overlap. The science infrastructure required to meet these needs also are described under objective 7.
- **Field studies to understand climate effects on population dynamics.** Process studies

and retrospective studies are core tools for the development and testing of conceptual models and identifying functional responses linking fish distribution, abundance, growth and phenology of fish and crab. In the case of the Bering Sea there is a 40 year history of recruitment studies on processes underlying recruitment of walleye pollock, biological and physical oceanography. These projects have provided an integrated understanding of several ecosystem processes within the region. Scientists within the AFSC continue to conduct retrospective studies to update time series with new observations to evaluate the skill of past relationships in predicting fish responses. The AFSC places a high priority on incorporating these proposed relationships into stock assessments, short-term stock projections, and long-term stock projections.

- **Ocean Acidification research.** Research focuses on commercially important fish and shellfish species and coldwater corals. The AFSC conducts studies on king and tanner crabs, coldwater corals, pollock, 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 of Alaskan crab fisheries are being used to forecast fishery performance for a range of climate and ocean acidification scenarios.
- **Fur seal research.** The most recent estimate of northern fur seal pup production on the Pribilof Islands indicated that the overall production had decreased by approximately 45% (annual rate of 3.7%, SE = 0.48%) since 1998. The reason for this steady decline is unknown, but may include direct and indirect effects of fishery competition as well as climate (e.g., mediated by prey availability and distribution). This trend is in contrast to the growing population of northern fur seals on Bogoslof Island to the south in the eastern Aleutian Islands. Possible demographic mechanisms are being assessed by collecting detailed life-history information in longitudinal studies of individually tagged animals. In summer and fall of 2015, the Marine Mammal Laboratory deployed 50 satellite tags on adult females and pups at St. George Island (20 adult females, 20 pups) and Bogoslof Island (10 adult females) to help understand potential behavioral and demographic responses of northern fur seals to environmental perturbations experienced during the winter migration as a result of ongoing El Nino conditions. In the summer of 2016 another project will use satellite telemetry to measure summer foraging behavior in relation to prey availability measured from the mid-water acoustic survey. This project will link fine-scale changes in fur seal foraging behavior with measures of pollock distribution and abundance in real time.
- **Economic effects of climate change.** Past research has focused on Bering sea pollock and cod and has shown that abundance, the size of the cold pool, and the age structure of the population interact with management actions (e.g., salmon bycatch measures) to determine the spatial and temporal distribution of fisheries. Current work is also underway on the Amendment 80 fishery. More work is needed on other species and to consider how to minimize the negative economic impacts on different stakeholders and

LMR dependent communities.

- **Social and human community effects of climate change.** To date, research on the effects of climate change on fisheries dependent communities has been limited to the development of indices related to community exposure to the bio-physical effects of climate change, community dependence on fisheries, and adaptive capacity for responding to the effects of climate change. Further research is needed to extend this higher level methodology to specific climate change impact projection scenarios so that AFSC can better understand how changes in recruitment and abundance will ultimately affect fisheries dependent communities.
- **Identify management interactions and bottlenecks.** Work is underway by biologists and economists to better understand the manner in which management actions interact with one another across fisheries. Through Management Strategy Evaluations (MSE), multi-species and multi-fleet models, and spatial economics models, researchers are working to identify specific policies that are likely to be limiting under a changing climate. More work is needed across all fisheries and managers should be informed of possible interactions as they are identified. Going forward, additional workgroups may be useful to work across agencies.

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

- **Alaska Integrated Ecosystem Assessment**s **and Alaska Marine Ecosystems Considerations.** The Ecosystem Considerations report is produced annually to summarize information about the Alaska Marine Ecosystem for the North Pacific Fishery Management Council, the scientific community and the public. The report includes ecosystem report cards (Figure 5), ecosystem assessments, and detailed ecosystem status and ecosystem-based management indicators for the Bering Sea, Aleutian Islands, Gulf of Alaska, and Arctic ecosystems. The report includes current climatic conditions as well as projections (e.g., 9 months) of physical and biological conditions that may impact fish and fishery productivity (e.g., cold-pool area).

  The integrated ecosystem assessment (IEA) program builds on the Ecosystem Considerations report 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.

- **Standard ecosystem monitoring.** Ecosystem trends are monitored through a combination of standardized groundfish and crab resource assessment surveys, fisheries oceanography, seabird, and marine mammal surveys, including ships of opportunity, diet collections, and fisheries observer collections. The standard set of fisheries oceanography surveys are spring and late summer cruises, occupied on a biennial basis, which cover much of the southeastern Bering Sea (Figure 5). In addition, four oceanographic moorings are located along the 70-m isobath. Seabird surveys often are conducted, usually aboard vessels of opportunity, including NOAA surveys. Marine mammal surveys are less common and typically are independent surveys (e.g., northern Bering Sea ice seal survey during 2012-2013). The surveys typically also monitor other aspects such as the food web (via diet collections) and bioenergetics.

Objective 7: Build and maintain the science infrastructure needed to fulfill NOAA Fisheries mandates with changing climate conditions.
Status: Ongoing.

- **Existing "Science Enterprise" including standard surveys and stock assessments** The mission of the Alaska Fisheries Science Center is to generate the scientific information and analysis necessary for the conservation, management, and utilization of the region's living marine resources. To meet this mission, the AFSC devotes more than 80% of its resources toward standard surveys, stock assessments of fish, crab and marine mammal populations, and the observer program. Our climate science strategy builds on this effort, which includes standard surveys for fish and crab species (bottom trawl, longline, midwater trawl/acoustics) as well as standard surveys for marine mammal species (most often aerial). Standard data collections occur for age, size, diet, and genetics. A large observer program monitors fisheries. These information sources are incorporated into fish, crab, and marine mammal stock assessments, which are used to provide quantitative advice for management of these species.
- **Recruitment Processes Alliance (RPA).** Research is conducted to understand processes affecting recruitment strength, including effects of climate. The research includes fieldwork, laboratory analysis of field sample collections (e.g., bioenergetics), laboratory studies, and modeling. A significant fraction of AFSC resources are invested in this effort (e.g., ~15% of labor). The Alliance joins the efforts of four AFSC programs: Recruitment Processes, Ecosystem Monitoring and Assessment, Recruitment Energetics and Coastal Assessment, and Resource Ecology and Ecosystem Modeling.
- **Loss of Sea Ice research.** Northern Bering Sea surveys will enumerate commercially important shelf species such as snow crab, yellowfin sole, and juvenile salmon which have distributions extending beyond the current area of of southeastern Bering Sea surveys. The additional survey effort will augment current annual coverage of the eastern Bering Sea shelf and will be repeated biennially.

- **Ocean Acidification research.** Research focuses on commercially important fish and shellfish species and coldwater corals. The AFSC conducts studies on king and tanner crabs, coldwater corals, pollock, 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 of Alaskan crab fisheries are being used to forecast fishery performance for a range of climate and ocean acidification scenarios.
- **Laboratory infrastructure.** Laboratories located in Juneau, Kodiak, Newport (OR), Seattle and on research vessels have a wide range of capabilities that help us to understand the mechanisms and effects of climate change. Salt water wet labs support process studies on the effects of temperature, ocean acidification, and contaminants on growth and survival of all life stages of fish and crabs. Insights into food web structure and function (trophic dynamics) are made possible by laboratory observations of lipids, stable isotopes, hydrocarbons, molecular genetics, primary productivity, taxonomic identification of ichthyoplankton and other types of zooplankton. Laboratories that measure the caloric content, growth, age and food habits of individual organisms make models of stock abundance, management strategy evaluations and ecosystem models possible.
- **Coastal assessments.** Nearshore habitats are essential to the functioning of marine ecosystems and LMR-dependent communities in Alaska. Climate change is accelerating the pace of coastal erosion, which determines the ability of coastal habitats to support LMR. AFSC coastal assessments are quantifying and identifying fish habitats in the eastern Bering Sea and elsewhere in Alaska through nearshore fish surveys and coastal habitat mapping.
- **Ecosystem modeling, ecosystem synthesis, and risk assessment.** Projecting future physical and biological conditions in the Bering Sea is a multi-institutional, collaborative effort. It requires coordination between physical modelers at PMEL and UW and fishery biologists at AFSC and UW who can couple biological and physical models through bioenergetic, habitat use, and food-web models of interactions. This requires additional personnel support to analyze data, parameterize models, and evaluate model results. It also requires ample access across facilities to core computers and data. Additionally, fundamental computing infrastructure needs to be maintained in order to run ROMS/NPZ and FEAST models for climate projections. This includes maintenance of the 164 core processor BEAST (or funds for some cloud-based alternative), as well as ample storage for archived completed model runs.
- **Assess economic impacts.** A critical element of an effective response to a changing climate is an understanding of the economic mechanisms through which fisheries develop, allocate effort, and target different species and sizes of fish. In addition,

management, markets, and the environment will all impact where processors and other fishing-related businesses grow or decline. By developing standing economic behavioral and regional economic models of all Alaska fisheries, we can evaluate how changing abundances and spatial distributions of different species impact communities and how management actions can best shape those impacts in the face of the uncertainties that we face. While some of this work can occur strictly within the economic discipline, it will also require ongoing interdisciplinary interaction among economics, other social scientists, biologists, fishery managers, and other stakeholders.

- **Assess community impacts.** There is a great need to link the projected and ultimate bio-physical effects of climate change to follow on impacts on LMR dependent human communities. While AFSC has started in this endeavor with the first iteration of an index of climate change exposure at the human community level, the analysis would greatly benefit from being updated and improved. Updating and improving this index would allow AFSC to better understand the effects of climate change on LMR-dependent human communities and develop management strategies to mitigate expected future impacts.
- **International coordination.** International scientific organizations such as PICES and ICES and bi-lateral partnerships such as Norway-US and Korea-US remain a key part of progress on climate science research. Activities include regional comparisons and climate and ecosystem model collaborations.
- **Critical partnerships.** The fisheries oceanography surveys of the AFSC in the eastern Bering Sea which are collectively known as the Recruitment Processes Alliance (RPA) leverage AFSC resources through partnerships in research programs active in the Alaska region such as those funded by the National Science Foundation (BEST), NMFS Office of Science and Technology (FATE), the North Pacific Anadromous Fish Commission (BASIS) Alaska Department of Fish and Game (Region III), Pacific Marine Environmental Lab (NOAA), North Pacific Research Board, North Slope Borough, the Bering Sea Fisherman's Association, the Alaska Sustainable Salmon Fund, and the Arctic Yukon Kuskokwim Sustainable Salmon Fund. The AFSC and the NMFS Alaska Region rely on a large number of data sources on fish landings, stocks, and prices that are collected by the State of Alaska. Current fiscal challenges faced by the State of Alaska may lead to changes in data collection and analysis that have the potential to present new and significant data gaps that may require additional NMFS resources in the future. It is very difficult to predict what changes may occur and when they are likely to happen.

ACTION PLAN

NMFS and the Council can take three important steps to improve efforts to identify and adapt to climate change impacts on federally managed fisheries in our region. 1) NMFS needs to be able to inform the North Pacific Fishery Management Council and industry with about a 10 year lead time, as to which commercially important species are likely to be "winners" and "losers" in regard to climate change in Alaska. These forecasts need to incorporate uncertainty.

Such forecasts would assist the Council in adjusting management programs (i.e., catch share programs) as necessary, and allow the industry to "tune" their capacity (e.g., number of fishing vessels) to match productivity, 2) NMFS and the Council need to identify and monitor thresholds in ecosystem parameters that signal the need to adjust management strategies, and 3) NMFS needs to continue on-going ship-based surveys to monitor changes in biomass, age-structure, and distribution of commercially important groundfish species in the Bering Sea and Gulf of Alaska.

In this section, we describe climate science activities planned for the next 3-5 years. The major actions are to: 1) continue research to identify the mechanisms of climate impacts on fisheries; 2) continue to track trends in ecosystems; 3) continue to identify future states of marine and coastal ecosystems; and 4) continue to identify robust strategies for fisheries management under changing climate conditions. The extent of progress will depend on funding levels. We will make some progress with level funding. Approximately $5M per year is spent to implement the Climate Science Strategy in our region as part of about $9M per year spent on process studies. The funding sources include the NOAA and NMFS programs of North Pacific Climate Regimes and Ecosystem Productivity (NPCREP), Integrated Ecosystem Assessment (IEA), Fisheries and the Environment (FATE), Stock Assessment Analysis and Modeling (SAAM), Loss of Sea Ice (LOSI), and Ocean Acidification (OA), as well as external funding from the North Pacific Research Board. The funding amount is approximate because more than one objective usually is supported (e.g., climate and ecosystems); project funds were partitioned to reflect support of multiple objectives. Progress on other Action Plans for other Large Marine Ecosystems in waters off Alaska will follow, as funding allows. This plan assumes two possible funding scenarios: 1) level funding; and 2) an increase of 10% above current funding.

Level funding

The extent of progress will depend on funding level. We will make some progress with level funding, though progress will mostly occur in areas such as monitoring trends, which are less expensive, than in the major, more expensive, challenge of gaining an understanding of the ecological processes that connect climate change to the productivity of fished populations. This understanding is required for quantitative forecasts of the impacts of climate change, which currently is limited to only 3 of 21 comprehensively assessed stocks in our region. With level funding, several projects will continue as described in the assessment. For example, the Ecosystems Considerations report will be produced annually and standard ecosystem monitoring, ocean acidification research, and climate-enhanced single-species projection modeling will continue. Here we list major projects identified in the assessment section which will continue with level funding in future years. Not all projects that will occur are listed here because of their number, but these unlisted projects can be found in the assessment section (e.g., Derive environmental indices from ocean models).

- **NPFMC Bering Sea Fisheries Ecosystem Plan.** Approved for development by the

North Pacific Fishery Management Council in December 2015.

- **Alaska CLIMate Project (ACLIM).** This project involves a suite of models designed to provide scenarios of future fish production under a variety of climate and fishing scenarios. This project will end with AR5/CMIP5 (IPCC Assessment Report/Climate Model Inter-comparison Project) projections in FY17 without more funding support.
- **Climate vulnerability assessment for the southeastern Bering Sea.** A climate vulnerability assessment for the southeastern Bering Sea, which will qualitatively assess species vulnerabilities to climate change and provide guidance on research prioritization, will be completed during 2016.
- **Belmont Forum project.** This project will synthesize information from regional studies to examine climate impacts in the marine ecosystems of the Pacific and Atlantic Arctic, which will be completed during 2017.
- **Recruitment Processes Alliance (RPA).** This ongoing research focuses on understanding recruitment processes of important southeastern Bering Sea fish species
- **Loss of Sea Ice research.** This effort extends standard surveys of the southeastern Bering Sea into the northern Bering Sea.
- **Ocean Acidification research.** This ongoing research focuses on commercially important fish and shellfish species and coldwater corals.
- **Fur seal research.** This project will link fine-scale changes in fur seal foraging behavior with measures of pollock distribution and abundance in real time.
- **Assess economic and human community impacts.** Modeling of the climate effects on fisheries and the related economic and human community impacts will continue.
- **Alaska Integrated Ecosystem Assessments and Alaska Marine Ecosystems Considerations.** The Ecosystem Considerations report is produced annually to summarize information about the Alaska Marine Ecosystem for the North Pacific Fishery Management Council, the scientific community and the public.
- **Standard ecosystem monitoring.** Ecosystem trends are monitored through a combination of ongoing standardized resource assessment surveys, fisheries oceanography, seabird, and marine mammal surveys, including ships of opportunity, diet collections, and observations collected by fisheries observers.
- **Advanced technology.** New technologies are opening windows and time periods unavailable to conventional methods for understanding prey fields and lower trophic level processes. A recent addition was acoustic estimates of euphausiid abundance. The newest technologies deployed in the last 1-2 years include upward-looking acoustics and sail drones.

Obvious limitations will occur with level funding. Funds are insufficient to pay for analysts and computing time on high-performance computers to model the ecological processes that connect climate change to the productivity of managed populations. As a result, new models will be delayed and some existing models may not be updated to present day. Computing senescence may also limit future modeling capacity without additional investment in replacement core processors. Existing model projections will stop with IPCC scenario AR5. A specific lapse is that ACLIM will end in FY17 without more funds.

Our climate science research program depends on continued funding of specific programs. Much of the current work is supported by the IEA program, NMFS S&T Economics, Social Sciences, Fisheries and the Environment (FATE), Stock Assessment and Analysis Methods (SAAM), and the North Pacific Climate Regimes, Ecosystem Productivity (NPCREP), and Loss of Sea Ice (LOSI). For example, economic and social science efforts are largely funded on a project-level basis so are highly dependent on annual S&T Economics and Social Science funds. We also will continue to need to write proposals to support project-specific investigations. With some additional funding, we would be able to provide a more integrated approach. In addition, such funding would support the permanent labor required to complete this work.

While climate-related impacts will continue to be an integral component of future research regardless of the level of funding, significant advancements in understanding of climate impacts on marine ecosystems in Alaska depend on integrated evaluations. For example, funding has supported major programs in the Bering Sea every 5-10 years. The most recent major integrated ecosystem research programs have been funded by the North Pacific Research Board and National Science Foundation for the Bering Sea and the Gulf of Alaska. Follow on research (the Recruitment Processes Alliance) is occurring for the Bering Sea Project. Under level funding, progress will likely continue to be project-based, opportunistic, and periodic around project-specific funds. Further, major program funding is necessary on the same tempo (every 5-10 years) to continue making substantial progress in understanding the ecosystem as a whole.

Diet data, needed to understand predator-prey interactions, is regularly collected and analyzed for four core species (walleye pollock, Pacific cod, arrowtooth flounder, and Pacific halibut), and sampling will likely continue for these species under level funding. A frustration with the current funding level has been that predator-prey interactions, which can be influenced by climate, have only been funded on an ad hoc basis for most species (beyond the core species), rather than receiving continuous funding.

Research on responses of fish and fisheries to changing climate conditions will continue to be an important aspect of AFSC's research enterprise. However, level funding limits proactive responses and pushes research and management into reactive responses. For example, research on climate and oceanographic factors influencing Prohibited Species Catch (PSC) in groundfish fisheries addresses a growing management issue, especially with respect to Pacific halibut and Pacific salmon bycatch, and may not be fully addressed with level funding.

Some additional funds

With some additional funds, depending on the amount, one or more of the following research areas would advance.

- **Fully support NOAA oceanographic moorings to monitor the ecosystem.** Currently, four oceanographic moorings are located along the 70-m isobath of the southeastern

Bering Sea, but NOAA covers only part of the funds required to continue this time series. Additional funds would fully support these existing moorings essential for providing valuable data for validating the ROMS/NPZ models.

- **Invest in modeling infrastructure.** Invest in computing time and storage on high-speed computers to model ecological processes and projections, as well as the analysts necessary to construct and operate these models, and analyze model outputs. Doing so will provide for new projections based on IPCC scenario AR6 and new management strategy evaluations based on NPFMC input. In particular, enhancing the existing high resolution ROMS/NPZ model to include freshwater inputs and refined nearshore dynamics in order to couple terrestrial and marine systems will provide foundation for near- and long-term projections of climate change driven changes to physical conditions in both offshore and nearshore areas. Investments related to the ROMS-NPZ would include: 1) the elaboration of software which can directly access the stored output from global models; 2) periodic tuning and refinement of the ROMS-NPZ model; 3) bias correction of the regional forcing and boundary terms, based on ROMS hindcasts; 4) exploration and testing of alternative parameterization and structural aspects of the zooplankton components; 5) maintenance of a searchable online system to query model output, e.g. to generate time series of relevant indices.
- **Comprehensive climate assessment completed every five years.** Operationalize the ACLIM projection modeling framework to facilitate the rapid uptake of the most recent IPCC global climate projections under a range of carbon emission scenarios, application of global projections into regional coupled physical-biological-economic models for the EBS, and coordination of iterative review with regional management councils and fishery stakeholders to evaluate the performance and implications of current and alternative "climate-ready" harvest strategies under future climate scenarios. The proposed iterative ACLIM framework conducted on a ~5 year cycle is modeled after the highly successful annual stock assessment cycle in the region; the approach will ensure that fisheries management decisions account for climate-driven changes to fish production and distribution and that climate-ready fisheries management in the region reflects the most recent global climate and carbon emission projections and best available ecosystem and socioeconomic science.
- **Invest in regional and international coordination.** Invest in coordination of AFSC climate research and fisheries projections with regional, national, and global efforts.
- **Integrate the evolving tools and data-integration work completed by AFSC and PMEL.** The synthesis and modeling of climate science and process research is data intensive. More investment is needed for data assimilation and repositories for model outputs. Some possibilities are to work with the Alaska Ocean Observing System to identify community-specific climate data that can be used to improve human community climate change vulnerability indices. Create a central repository for climate data, including geographic-based climate data.

- **Invest in understanding fish and shellfish adaptations to climate change.** Studies of the impacts of climate drivers (ocean and OA) on phenologies of life cycle attributes. How does OA change maturation rates of core species? How are birth, growth and mortality rates of core species coupled to temperature? Funding is currently limited and only sporadically available through temporary funds. To more fully assess the adaptive capacities of managed resources additional funds are needed to get the information above by conducting laboratory experiments, and making field observations to assess interannual variability in climate variables and fish and shellfish vital rates to gain knowledge of the functional relationships governing fish and shellfish responses to changing climate.
- **Invest in understanding the effect of climate on fur seal foraging.** Direct and indirect (i.e., mediated by prey) effects of climate may affect fur seal foraging, their reproductive success, and thus their population trends, which have been declining in the eastern Bering Sea.
- Expand research to **understand how climate change will impact fisheries through changes in the distribution of target and prohibited species** (e.g., salmon and halibut) and how this will impact fishery-dependent communities.
- **Improve communication of the risks of climate change to fishing dependent communities** (e.g., expected and known changes to important LMR food sources and economically important LMRs), **the North Pacific Fishery Management 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 could involve informational interactive websites, glossy brochures and other products that could disseminate the impacts of climate change on LMRs and the expected follow on impact to LMR users.
- **Invest in training and education.** There is an overall paucity of scientists who are trained in interdisciplinary science that bridges meteorology, oceanography, fisheries oceanography and fisheries management.

A long-term challenge

A long-term challenge is to design adaptive decision processes that can incorporate and respond to changing climate conditions. Preparing to address this long-term challenge will likely occur during the next 3-5 years. What is not well worked out is how and when does the North Pacific Fishery Management Council (Council) react to climate-induced reference point changes, an area that needs considerable attention, discussion, and education. This discussion should involve the Plan Teams, Science and Statistical Committee, and Ecosystem Committee, all subsidiary bodies of the Council, as well as the Alaska Regional Office.In December 2015, the Council decided to go forward with a Bering Sea Fisheries Ecosystem Plan, which includes a climate module. Identify short-term management approaches that should be preserved going forward (e.g., EBFM policies, adaptive management approaches), long-term (i.e., multi-decadal) management measures should be systematically reevaluated for continued performance (e.g., MPA effectiveness, upper or lower biomass thresholds), and EIS studies should be conducted for growing or novel fisheries of species expected to thrive under future conditions.

TIMELINE AND METRICS

Project	**2016**	**2017**	**2018**	**2019**	**2020**
NPFMC Fisheries Ecosystem Plan, climate module	X	X	X		
Alaska CLIMate Project (ACLIM)	X	X	X		
Climate vulnerability assessment for the southeastern Bering Sea	X				
Belmont Forum project	X	X	X		
Recruitment Processes Alliance	X	X	X	X	X
Loss of Sea Ice research	X	X	X	X	X
Ocean Acidification research	X	X	X	X	X
Fur seal research	X	X	X	X	X
Assess economic and human community impacts	X	X	X	X	X
Alaska Integrated Ecosystem Assessments and Alaska Marine Ecosystems Considerations	X	X	X	X	X
Standard ecosystem monitoring	X	X	X	X	X

Project	Metrics
NPFMC Fisheries Ecosystem Plan, climate module	The climate module would: 1) synthesize current climate change project outcomes; 2) prioritize species for MSE evaluation; and 3) run MSEs on specific species and scenarios identified by the Council.
Alaska CLIMate Project (ACLIM)	Scenarios of future fish production and distribution under a variety of climate and fishing scenarios.
Climate vulnerability assessment for the southeastern Bering Sea	Qualitative assessment of species vulnerabilities to climate change and guidance on research prioritization.
Belmont Forum project	1) Review and synthesize impacts of climate change on components of Arctic marine ecosystems; 2) compare and contrast the impacts in the Atlantic and Pacific sectors of the Arctic; 3) review the ability of current management frameworks to adapt to likely future changes.
Recruitment Processes Alliance	Understand processes affecting recruitment strength, including effects of climate, on selected cod, flatfish, and salmon species.
Loss of Sea Ice research	Biennial surveys of the northern Bering Sea.
Ocean Acidification research	Understand ocean acidification effects on king and tanner crabs, coldwater corals, pollock, cod and northern rock sole.
Fur seal research	Understand differing fur seal population trends at the Pribilof Islands and Bogoslof Island.
Assess economic and human community impacts	Understand economic and human community impacts of climate change.
Alaska Integrated Ecosystem Assessments	Annually produce Ecosystem Considerations

and Alaska Marine Ecosystems Considerations	report including report cards, assessments and detailed ecosystem status and ecosystem-based management indicators.
Standard ecosystem monitoring	Conduct biennial spring and late summer cruises. Maintain four oceanographic moorings located along the 70-m isobath.

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FIGURES

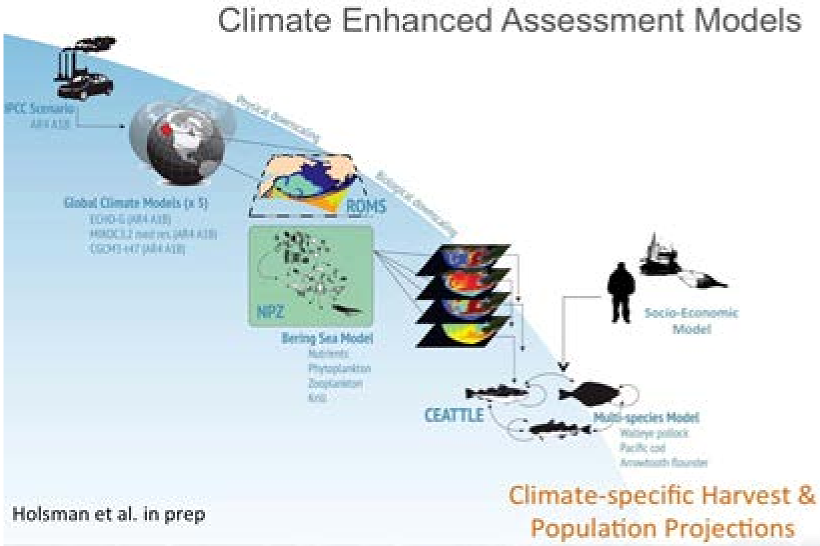

Figure 1. Example of climate-enhanced multi-species model with socio-economic module.

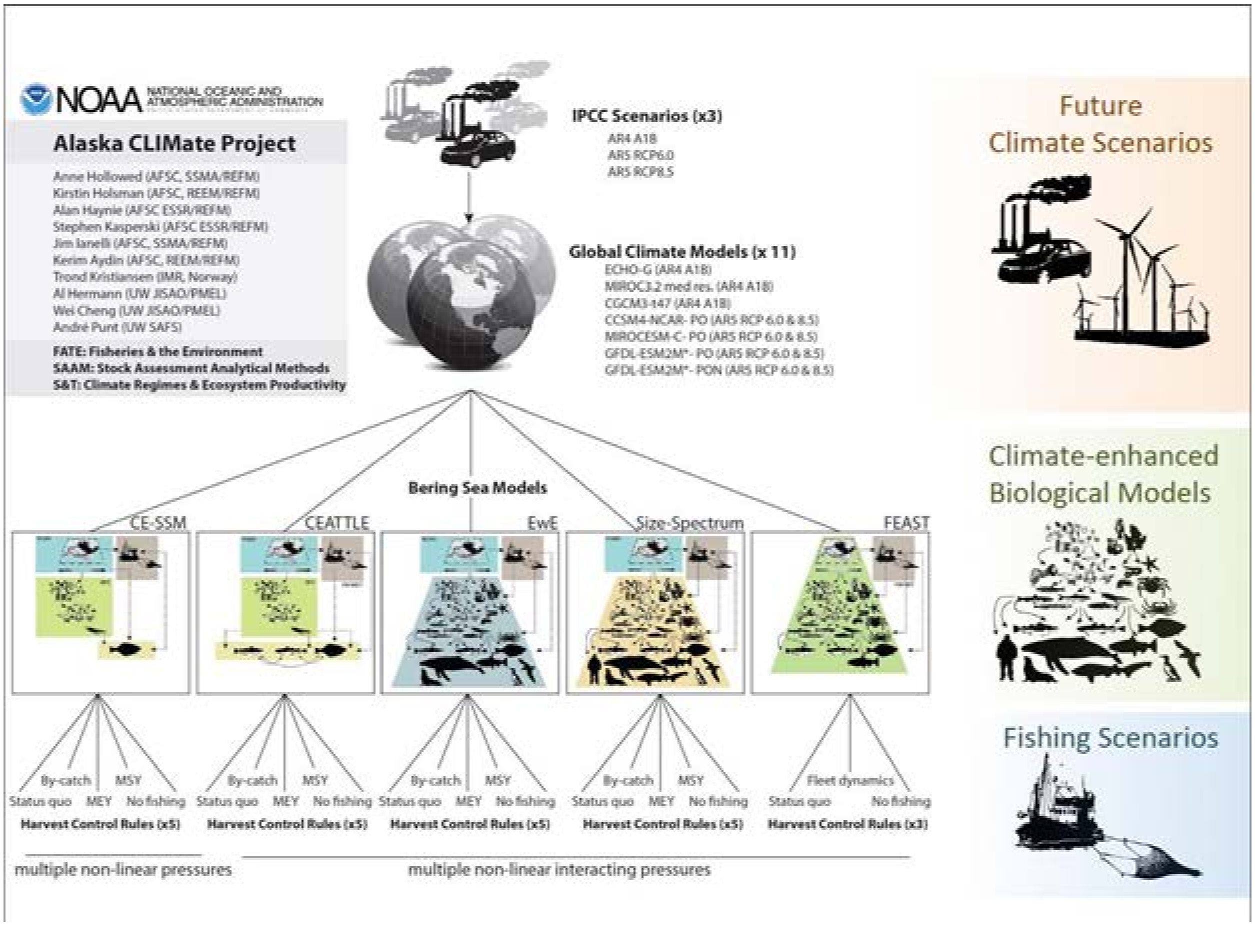

Figure 2. Illustration of the multiple models and climate and fishing scenarios in the ACLIM project.

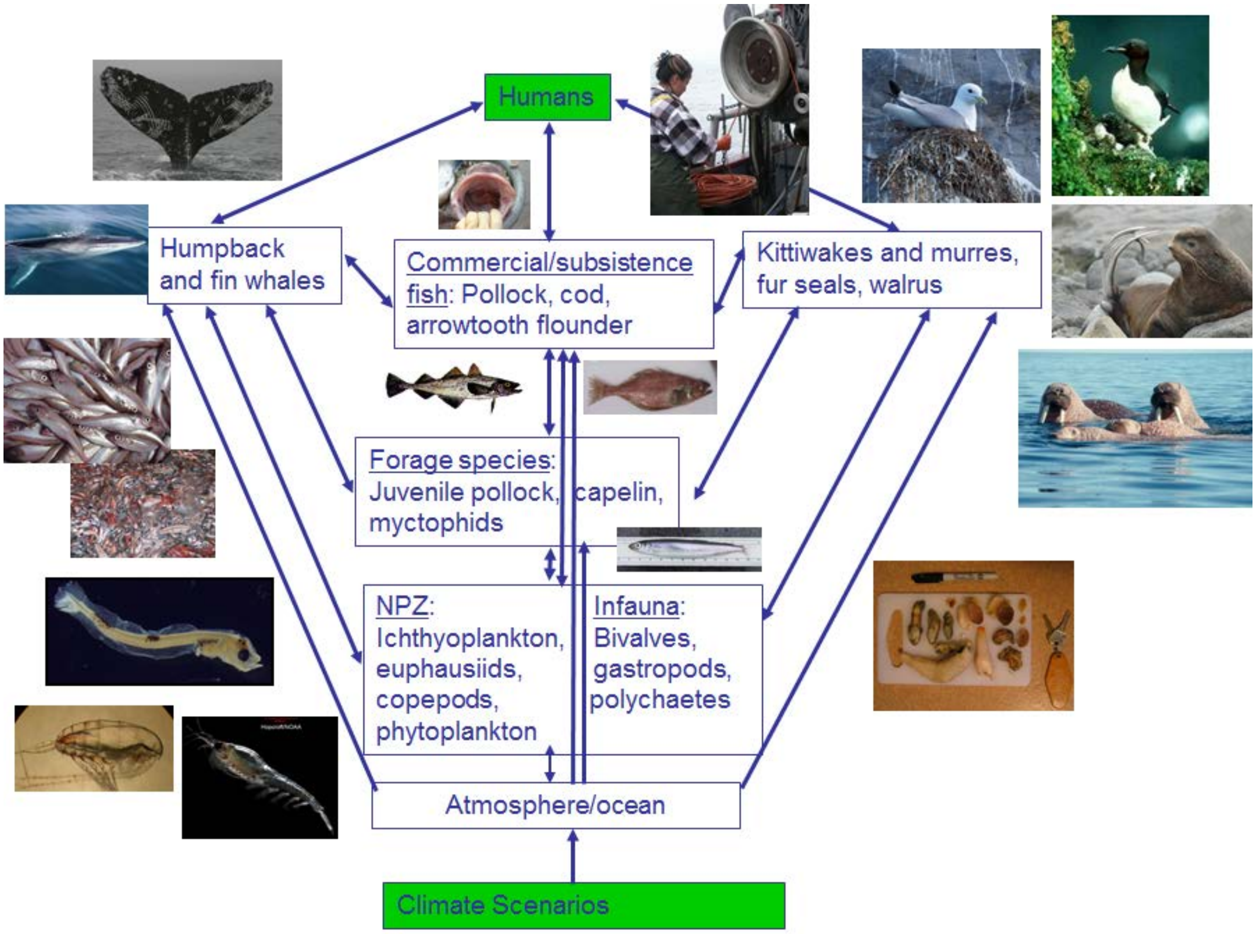

Figure 3. Scientific scope of the Bering Sea Project. The links and species shown here were studied in this project.

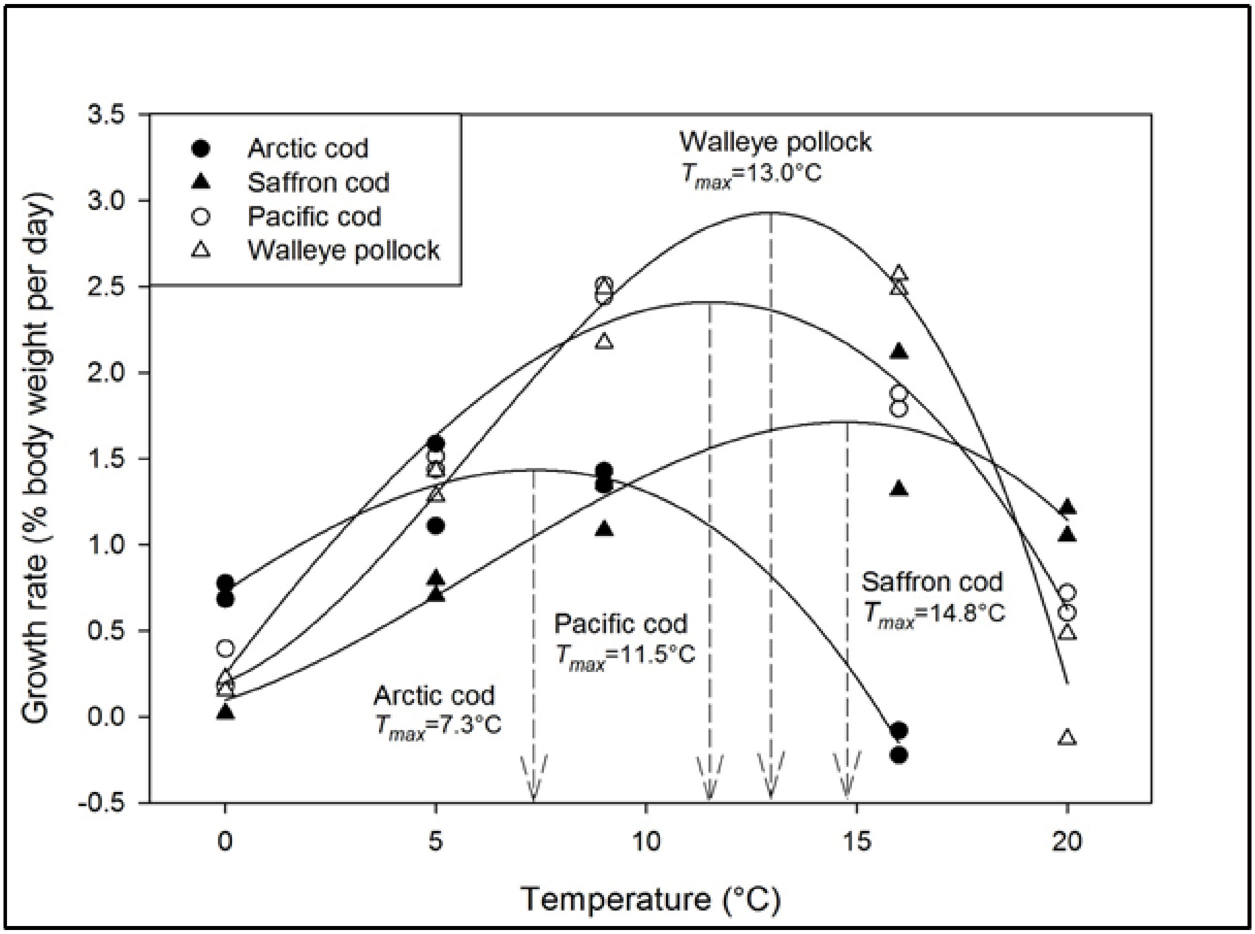

Figure 4. Example of laboratory research related to climate change. Growth response in relation to temperature of four cod species (Laurel et al., 2015).

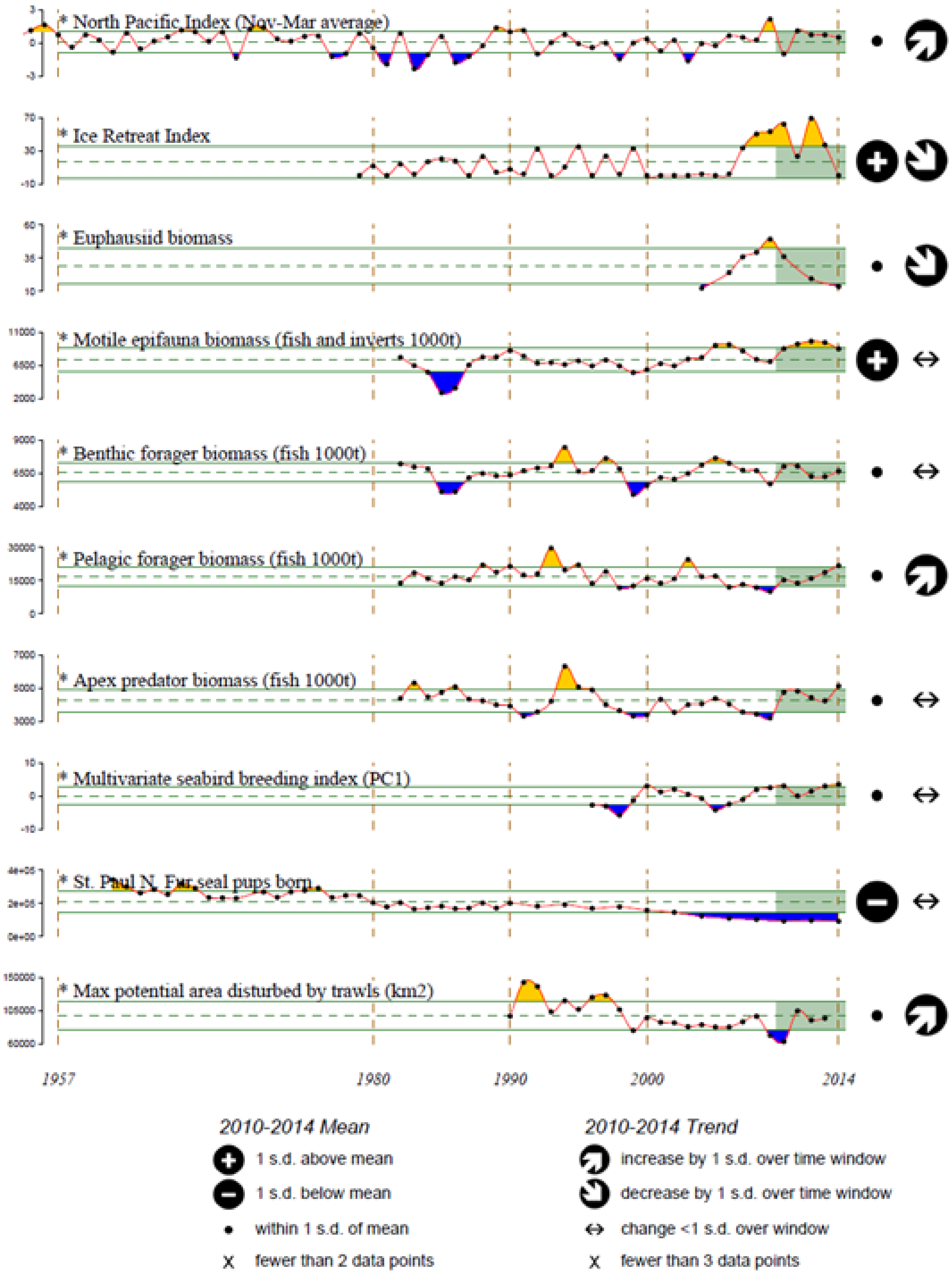

Figure 4. Example of ecosystem report card for the eastern Bering Sea (Zador et al., 2015).

Figure 5. Example of ecosystem monitoring survey; the example survey (BASIS) occurs biennially during late summer (http://www.afsc.noaa.gov/ABL/EMA/EMA_default.php).