Final SSC February 2023 Workshop Report

Rapid change in the northern Bering and southern Chukchi Seas - Identifying ecosystem responses and effects on the management of Federal fisheries

North Pacific Fishery Management Council - Science and Statistical Committee Workshop

February 7-8, 2023

FINAL REPORT

Overview

On February 7-8, 2023 the North Pacific Fisheries Management Council – Science and Statistical Committee (SSC) held a workshop titled "*Rapid change in the northern Bering and southern Chukchi seas – Identifying ecosystem responses and effects on the management of Federal fisheries*" (Appendix 1). The workshop was motivated by recent rapid changes in the Pacific Arctic and, in particular, in the northern Bering Sea (NBS) and Bering Strait region. A number of Bering Sea commercial fish stocks moved into and possibly beyond the northern Bering Sea and their abundances in these areas increased dramatically during a recent marine heatwave. These changes have resulted in increased uncertainty about the status of Bering Sea stocks, as exemplified by the sudden and unexpected decline of snow crab and large scale movements of Pacific cod following an unprecedented warm period. There is a need to better understand the role of the NBS and southern Chukchi Sea ecosystems in supporting Bering Sea commercial fish and shellfish stocks, and – in turn – to understand the impacts of a northward expansion of Bering Sea fish stocks on the NBS ecosystem.

As Bill Tweit (NPFMC) noted in his opening remarks, the Council faces unprecedented challenges about how to balance protecting livelihoods and ways of life with sustainable harvests during a time of rapid change, as well as increased scrutiny and social conflict. He focused on four critical issues: understanding the limitations of current tools for decision making, concerns about litigation against new tools and approaches that could inhibit the adoption of new strategies, the need for clear demonstrations of how EBFM will help the Council adapt, and the lack of proficiency and familiarity with applications of risk-based management approaches. In approaching these challenges, he emphasized the importance of communication throughout, such as integrating different perspectives including indigenous knowledge, recognizing the social as well as scientific issues in selecting ecosystem indicators to use in management, and acknowledging that adaptive management requires trust among participants. Effective strategies will include the choice of accessible vocabulary, broadening our listening skills, encouraging creativity, and eliminating communication hierarchies. As we develop new management frameworks, as much thought must be given to inclusion, communication, implementation and defensibility as to the development itself.

These challenges and strategies echo themes identified during the SCS7 workshop, *Adapting Fisheries Management to A Changing Ecosystem,* and its key findings. Findings were summarized by Diana Stram at the beginning of this workshop and included the need for Councils to prepare now for complex management decisions due to climate change, the need for investing in the development of new data collection and analysis tools that are responsive to changing conditions, the need for SSCs and Councils to transition towards more sophisticated tools and approaches, and the critical role of stakeholder engagement for adaptive management to be successful.

The workshop included opportunities for open discussions among SSC members, among the SSC and subject matter experts, and among the SSC and Council members. Ample opportunities were also provided for the public and a wide variety of stakeholders to comment on the challenges the Council faces and to participate in these discussions. The SSC workshop was part of an emerging dialogue among the SSC, scientists working in the NBS, other knowledge holders from the NBS and other interested stakeholders.

Many issues were raised during the workshop to inform and support the work that is needed to develop the scientific basis for managing Bering Sea fish stocks in a time of unprecedented changes. This is especially critical given the expanding footprint of Bering Sea fish populations into habitats that previously were dominated by an Arctic fish assemblage and that provide the food and livelihoods for people in the region.

The goal of the workshop was to identify the science and monitoring requirements for supporting future Council decision-making under increased uncertainty. This included exploration of proactive approaches for achieving management goals in a changing environment, and an assessment of how existing frameworks may or may not be able to address ecosystem variability. To achieve this goal, session objectives included an assessment of our current understanding of the major changes occurring in the NBS that affect all components of the ecosystem (Session 1), identification of critical gaps in understanding, as well as research and monitoring needs to address these gaps and to adequately assess ecosystem status and trends (Session 2), and assessment of the tools and approaches currently used or needed in the future to manage Bering Sea fish and crab stocks (Session 3).

SESSION 1. WHAT DO WE KNOW ABOUT THE CURRENT STATE AND NEAR-TERM FUTURE ENVIRONMENTAL AND ECOLOGICAL STATES OF THE NORTHERN BERING SEA AND SOUTHERN CHUKCHI SEA?

Summary of key indicators of change

Physical environment: This session started with a description of and recent changes to the physical environment and climate trends in the region (Seth Danielson, UAF). Key processes associated with dynamic water flow, typically driven by winds, have changed with environmental conditions. The overall net flux of heat to the north has increased, with excess heat gain measured in the Chukchi Sea relative to the North Pacific. The result of this flux was observed in the sea ice conveyor belt and cold pool characteristics. These changes have potential consequences for species distributions, species' metabolism, food quality, competition for resources, and pelagic export to the benthos. The presentation concluded by highlighting some characteristics of the Northern Bering Sea that will likely persist in a warming climate, including extreme seasonality, large nutrient fluxes that drive primary productivity, and diatoms that sink to the seafloor to sustain high benthic production. Questions were raised about the quality of sea ice habitat, the impact of increased shipping on sea ice habitat, and the changing contribution of sea ice algae to the annual production and to the benthos, which are poorly understood at present.

Plankton and epibenthic invertebrates: Lower trophic level responses to environmental changes were considered for phytoplankton and zooplankton (Dave Kimmel and Lisa Eisner, AFSC), epibenthic invertebrate community diversity (Lauren Sutton, Kachemak Bay NERR), and epibenthic infaunal biomass (Libby Logerwell, AFSC). Recent work supports the hypothesis that warming and earlier sea ice retreat have favored a shift to longer food chains (and lower carbon flux to the benthos), starting with smaller phytoplankton and microzooplankton species. The role of larger, fatty zooplankton such as *Calanus* will change as it may no longer accumulate in large numbers on the shelf in the absence of the cold pool. This reduces food availability for small fish, and may reduce the potential for the ecosystem to support key fish species. It is possible that euphausiids may replace *Calanus* as important food in warmer years, but the abundance of euphausiids is poorly known as they are difficult to sample. In addition to changing abundances, changes in bloom timing may affect all trophic levels. For example, in 2018 in the northern Bering Sea earlier ice retreat led to a delayed phytoplankton bloom that was decoupled from the ice retreat. The number of open water blooms is expected to increase as the ice edge retreats northward and sea ice melts earlier, with unknown effects on overall phytoplankton biomass and productivity.

A retrospective analysis of epibenthic invertebrates in the northern Bering Sea and Chukchi Sea suggests that functional groups have changed from more sessile invertebrates to more crawlers and swimmers during the recent warm years from 2015-2019 and these trends are expected to continue through the end of the century. At the same time, infaunal biomass from 1998-2018 decreased in southern regions of the northern Bering Sea while increasing north of the Bering Strait. As temperatures continue to change, the habitat for

some species shifts to the north and shrinks, in particular cold water habitat for some snails and mussels that provide important food for seabirds, mammals and flatfish. Similarly, the preferred habitat for snow crab will shrink, while warm water habitat will expand, along with warm-water invertebrates that have a broad temperature tolerance such as basket stars.

Seabirds, marine mammals, and groundfish: Upper trophic level responses to the observed environmental changes were considered for seabirds (Adrian Gall, ABR Inc., and Robb Kaler, USFWS), marine mammals (Michael Cameron, AFSC), and commercial groundfish species (Franz Mueter, UAF, SSC member, Kerim Aydin, AFSC, and Lauren Rogers, AFSC). Seabirds were identified as useful ecosystem indicators because their distribution, abundance and reproductive success reflect the location, abundance, composition and quality of suitable prey. Seabirds have been concentrated offshore during previous marine heatwaves and the abundance and distribution of seabirds changed substantially during the recent marine heatwave beginning in 2014/15. Fish eating seabird species moved to the north while plankton eaters stayed in the northern Bering Sea in 2017-2019 compared to earlier years. The diet of plankton eating auklets that stayed in the northern Bering Sea during this period consisted almost entirely of euphausiids, rather than the more mixed diet of copepods, euphausiids and other zooplankton that characterized diets in earlier years. Murre, kittiwake and auklet colonies throughout the region experienced reproductive failures during the heatwave (2016-19) and widespread die-offs of both plankton eaters and fish eaters were observed during the same period and have been linked to nutritional stress. The abundance of seabirds at many breeding colonies in the Bering Sea has declined, while the abundance of kittiwakes and murres at Cape Lisburne in the Chukchi Sea increased despite reproductive failures, suggesting immigration towards this northern colony from the south. Participants highlighted concerns over seabird die-offs due to poor food availability and commented that local residents in the Bering Strait region have a wealth of information on seabird trends and condition.

Similar to seabirds, marine mammals can serve as indicators of a changing northern Bering Sea ecosystem, in particular species closely associated with sea ice. Sea-ice dependent ice seals experienced a decline in body condition during the marine heatwave, due to loss of habitat and nutritional stress. Poor body condition led to low pup survival as well as mortalities of some subadults and adults. Due to their dependence on sea ice, and despite high abundances, bearded and ringed seals have been listed as “threatened” and critical habitat has been designated for both species. While interactions with fisheries are rare, these could increase if more fisheries expand into the northern Bering Sea. The abundance and distribution of whales in the Bering and Chukchi seas is also changing as sea ice cover and temperature change. For example, the overwintering distribution of endangered bowhead whales has shifted from the Southeast Bering Sea into the northern Bering Sea and southern Chukchi Sea, with the potential to change their interactions with fisheries that can entangle or strike whales. An unusual mortality event for grey whales occurred primarily along the US West Coast, but has been attributed to poor foraging conditions in the northern Bering Sea and Chukchi Sea. There is also concern for endangered North Pacific Right Whales, which have been observed in the Bering Strait region. Workshop participants highlighted that the four species of ice-associated seals are essential to the nutritional, economic and cultural needs of communities throughout the Bering Strait region.

Changes in temperatures and ice cover during the marine heatwave were associated with changes at the base of the food chain that not only impacted seabirds and mammals, but had a profound impact on the distribution of several commercial groundfish species. In particular, during warm years, wholesale distributional shifts to the north were noted in Pacific cod, walleye pollock and other subarctic species, whereas a cold water assemblage of more Arctic species shrank back to a much more limited northerly distribution. The expansion of large migratory fish species into the NBS increased the overall consumption of prey resources in this region by groundfish predators, likely competing with seabird and marine mammal predators for available prey. The estimated consumption peaked in 2017 in the Chirikov Basin north of St. Lawrence Island, but not until 2019 in other areas of the NBS. While pollock primarily consumed pelagic prey, Pacific cod primarily consumed benthic invertebrates including a large proportion of snow crab,

which likely contributed to a pronounced decrease in benthic biomass on the NBS shelf after 2019. Tagging studies suggest that Pacific cod use the NBS seasonally for feeding and disperse to spawning locations along the outer shelf and slope, including Russian waters, in winter. Spawning habitat for Pacific cod is projected to expand onto the shelf but the NBS is not predicted to become thermally suitable for Pacific cod spawning based on lab-derived estimates of hatching success and projected temperatures on the shelf through the end of the century. However, recent warming on the Bering Sea shelf has already exceeded levels that were not expected for several decades.

Discussion: During the open mic session and SSC discussions, participants identified a number of core themes and highlighted some of the challenges facing the region, including:

- The pervasive, ecosystem-wide changes that were observed following the recent marine heatwaves suggest a change in how the energy captured by primary producers is transferred to higher trophic level predators and a possible change in the number of seabirds and mammals the region can support (carrying capacity). **This has important consequences for food security in a region that is heavily dependent on the marine environment.**
- The NBS is relatively under-studied in terms of key processes and the length of available time series. Important knowledge gaps limit our understanding of ecosystem processes and food web dynamics. Specifically, it is unclear how changes in the timing, quantity and quality of sea ice, the changing dynamics of ice-associated algae, and the expansion of predatory groundfish into the NBS has already modified the NBS ecosystem and will continue to affect all ecosystem components in the future. **Addressing these knowledge gaps will require a coordinated approach to understanding the ongoing changes through improved monitoring and process studies**.
- A recurring theme was connectivity among different regions and the need to better understand and account for these connections. A number of eastern Bering Sea groundfish stocks have extended their distributions into the NBS, into Russian waters, and into the Chukchi Sea. Participants highlighted work that is underway to understand these connections, such as tagging studies, acoustic moorings to track movements across the dateline and genetic work to understand population connectivity. **There is a need for increased collaboration and coordination not just within the region but also with Russian scientists and managers** to address emerging transboundary issues. Despite challenges associated with the current geopolitical environment, there are ongoing collaborations with Russian scientists (e.g., through PICES, WWF) that can provide a foundation to build on.
- Participants also highlighted the **potential for NBS residents to contribute data and information on many aspects of the ecosystem such as ice conditions, seabird and mammal diets, body condition of harvested animals, presence of parasites or injuries, and many other aspects.** The challenges associated with incorporating local knowledge and traditional knowledge into the Council's decision-making process were noted, as were efforts to identify appropriate 'on-ramps' led by the LKTK taskforce.
- There are many opportunities for sharing information, co-producing knowledge, and co-management approaches, but **these will require improved coordination among agencies and between agencies and local / tribal governments due to multiple jurisdictions with overlapping authorities and responsibilities.** Participants also noted the general increase in human activity (e.g., shipping) in the region that requires consideration of other sectors in Council decision making.

- Finally, it was noted that in order to implement ecosystem-based fisheries management in the NBS, and to develop the science required to support it, the Council in collaboration with NBS residents should identify appropriate goals and objectives for fisheries management that may be specific to this region. **A review of ecosystem-level objectives, including the need for regional objectives, could be undertaken as part of a Programmatic EIS if and when it is initiated.**

Specific data gaps, research needs and recommendations that emerged during session 1 from either the presentations or public input are included in the list of recommendations below.

SESSION 2. WHAT DATA DO WE NEED TO COLLECT OR MONITOR IN THE NORTHERN BERING SEA AND THE SOUTHERN CHUKCHI SEA?

During Session 2, the SSC discussed the need for resources and ecosystem surveys, biological information, ecosystem considerations, and other sources of knowledge. We provide a brief overview of the discussions before listing key gaps and data needs that were identified during either session 1 or session 2. The list summarizes the main points that were brought forward during presentations, open mic sessions and SSC discussions, but will require further synthesis and prioritization.

Fish and ecosystem surveys

The core NOAA Fisheries surveys conducted in the NBS include recent increases in bottom trawl surveys starting in 2010, 2017-2019, and annually since 2021. Demersal survey index data are beginning to be incorporated in some stock assessments. Acoustic surveys are periodically conducted in the NBS to assess pelagic backscatter. The NOAA Fisheries/Alaska Department of Fish and Game ecosystem and salmon survey has been annually conducted since 2002. The data collections include oceanography, zooplankton, juvenile gadids and salmon, forage fish, and recently benthic data, including juvenile crab and flatfish abundance and condition. Data are used in salmon forecasts, Ecosystem Status Reports (ESRs), and Ecosystem and Socioeconomic Profiles (ESPs). Tagging studies on Pacific cod and Pacific halibut have been particularly informative on movement patterns relative to seasonal environmental conditions.

In the Chukchi Sea, periodic surveys of various trophic levels (physics, plankton, forage fish, benthic species) have been conducted between 2000 and 2018 under various programs. Ongoing surveys in the region include physical and biological oceanographic data collected under the multi-agency supported Distributed Biological Observatory (DBO) program.

Motivation for additional surveys in the Chukchi Sea region include monitoring the proportion of EBS groundfish and crab stocks moving out of the EBS Fishery Management Plan (FMP) region, establishing an ecosystem baseline, validation of predictive ecosystem models, and assessment of non-fisheries activities in the region such as oil and gas development and increased shipping.

Discussions were focused on what the periodicity of surveys should be in the NBS and the potential for surveying fish stocks in the Chukchi Sea. **The SSC commented on the critical importance of the regular and area-wide fish and ecosystem surveys and recommended that new resources support the necessary data collection in the Chukchi Sea.**

The potential for ecosystem surveys in the Chukchi Sea were also discussed. It was noted that resource limitations in other Alaska regions may prevent survey opportunities in the Chukchi Sea. **Partnerships and comprehensive/integrated surveys will be necessary to build capacity for data collection in the Chukchi Sea and should be focused on ecosystem understanding and fish surveys that could support stock assessments.** Improved sampling designs and innovative data collection tools should be considered. It was noted that identification of the certainty required in stock assessment surveys will be important to designing expanded surveys in this region.

Biological information needs

The SSC discussed basic biological information that should be considered to track changes in the NBS and Chukchi Sea. The importance of increasing focus on coordinated tracking of the movement of fish and marine mammals was noted. However, indexing movement from moorings versus tracking a few individuals should be evaluated. Collecting environmental data and vital rate data concurrently may be an innovative means of increasing data availability. Expanding sampling through community involvement can support frequent, systematic, and comprehensive sampling. **Considering key bottlenecks (e.g. recruitment) will help refine data collection on appropriate aspects of the ecosystem.** With changing environmental conditions, there may also be a need for more periodic growth and maturity assessments that inform stock assessments.

List of knowledge gaps, monitoring needs, and tools

Specific data, information, and knowledge gaps; unmet monitoring goals; and tools needed to advance key data collections that emerged from discussion during sessions 1 and 2 are listed below, but have not been fully synthesized nor priortized yet.

Data/information/knowledge gaps

In the development of key indicators of change noted in this region, gaps were noted in the data, information, and/or knowledge available to consider for observing or monitoring the changes.

- The predictability of temperature "stanzas" relative to extreme events that may be tested with existing regional climate models.
- Identification and importance of aggregating processes (frontal zones) and their variability.
- Role of ice-associated algae in changing sea ice ecosystems.
- Euphausiid requirements for fish and seabird species at a time when large, ice-associated Calanus zooplankton may be declining.
- Pelagic and benthic juvenile fish, crab, and prey condition, abundance, and distribution, including juvenile life stages of commercially important species.
- Taxonomic expertise for species identificatons, particularly for lower trophic levels, to effectively monitor ecosystems for continued changes and support ecosystem research.
- Species and life history-specific physiological thresholds and tolerances to temperature and ocean acidification, considering the subsequent effects on ecosystem production.
- Physiological responses (growth and maturity) and temperature thresholds of commercial species to understand effects of extreme events and the potential for recovery in between events.
- Expected distributional shifts, changes in movement patterns and rates, and what the effects are on connectivity among the ecosystem in the region.
- Suitability of the NBS as spawning (e.g. cod, pollock) or nursery habitat and the potential role of the Chukchi Sea as juvenile or adult summer habitat.
- Effects of fishing gear on unobserved mortality and habitat in the NBS ecosystem.
- Carrying capacity for commercial fish in the NBS under increased predation pressure caused by distribution shifts, including summer feeding movement and potential lateral expansion to the western Bering Sea shelf.
- The resilience of the NBS ecosystem if cooler conditions return and distributions return to previous states.

- Specific causes of seabird and marine mammal mortality events related to changing prey availability.
- Productivity trade-offs between feeding success and haulout requirements for juvenile ice seals and how it relates to the capacity of the system to support ice seals.
- Comparative analyses with other polar regions that experience similar climate-change forcing (including sea ice loss), have a history of commercial exploitation, and are home to communities dependent on marine ecosystems.
- Capacity building through coordinated data collection and processing across projects and programs (including industry partnerships, communities, and through academic programs) to build capacity.
- Social science capacity, including quantitative expertise, to address impacts on fishery- and subsistence-dependent communities from fisheries management decisions and climate change.
- Identification of human indicators of change and community-based prioritization of species (e.g. marine mammals) that require further study.
- Traditional ecological knowledge, local knowledge and Indigenous knowledge from northern communities and co-management entities to incorporate into the understanding of ecosystem processes and ongoing changes.
- Traditional and local knowledge from industry groups to inform biological understanding, research priorities, analytical products, and decisions.

Unmet monitoring needs

These are specific items that were identified as important but need additional monitoring to better understand changing processes.

- Sea ice characteristics and subsequent changes in the cold pool, thermal dynamics, and salinity dynamics.
- Seasonal changes in hypoxic conditions occurring in benthic ecosystems.
- More seasonal (Spring-Fall) phytoplankton and zooplankton composition data and timing relative to temperature and total production.
- Infaunal/epifaunal species composition, functional/taxonomic diversity, and abundance (e.g. through eDNA or meta-barcoding approaches) relative to pH and temperature trends if coupling to broader ecosystem processes and fish stocks can be shown.
- Benthic sedimentation to track interannual changes and trends in pelagic-benthic coupling.
- Expanded sampling (acoustic, nets) of forage fish species and nearshore juvenile fish.
- Upper trophic levels species composition and abundance (e.g. vessels of opportunity, eDNA) with focus on community-specific data collection (sea bird and marine mammal mortality events; seabird production, condition, and biological samples).
- Expanded food habits studies to inform our understanding of trophic changes.
- EBS slope survey to inform a fuller understanding of the EBS/NBS ecosystem.

Specific tools that need to be developed to advance key data collection

- Genomic approaches for rapid and efficient phytoplankton, zooplankton, infauna/epifauna identification (e.g., DNA meta-barcoding, eDNA).
- Research and development of tools (e.g. acoustics, nets) for euphausiid sampling.
- Gear innovation that improves interactions with habitat and other species.
- Imaging technology to improve plankton assessment (CytoBOT) and to track movement of pelagic species (e.g. pollock) from mooring data.
- Efficient and effective collection of local and traditional knowledge that fills information gaps on ecosystem processes, community sustainability, and subsistence interactions with commercial fisheries.
- Better use of remote sensing (ship-board or mooring-based acoustic data collection, satellite-based observations, tagging marine mammals) to gather ecosystem information.

SESSION 3. WHAT TOOLS DO WE HAVE OR NEED TO APPLY THESE DATA TO MANAGEMENT OF BERING SEA FISHERIES?

This session aimed to assess whether current tools and approaches used by the Council, including assessment models, the tier system, and current harvest control rules (HCR), are adequate to deal with the management challenges that arise under increased uncertainty, or whether we need to consider novel approaches to deal with a rapidly changing, and increasingly non-stationary environment. While many gaps remain in our understanding of the northern Bering Sea, much has been learned in recent years that can be integrated with our understanding of the Bering Sea ecosystem more broadly to better inform the management of Bering Sea stocks in light of the ongoing changes. **Any next steps need to be considered in the context of the many processes that are already underway**, such as the Alaska Climate Integrated Modeling Project (ACLIM), NOAA's Climate, Ecosystems, and Fisheries Initiative (CEFI), and the work of the Climate Change Task Force, and the LKTKS Task Force, **or processes that are in the planning stages**, such as the newly initiated process to consider a Programmatic EIS.

The workshop received a presentation by Kirstin Holsman (AFSC) on the potential for improving the predictive capacity of climate-informed ecosystem models to support the management of commercial fish species. Much of the work presented was based on ACLIM results. The presentation highlighted ongoing work to model the effects of downscaled climate predictions on the Bering Sea ecosystems, including initial applications to project future trends in the physics, chemistry, zooplankton and key fish stocks through the end of the century. Of particular interest to the Council, preliminary results from ongoing work to evaluate the performance of alternative HCRs and the 2 MT cap on groundfish removals were summarized. It was noted that, while there has been considerable progress on the physical and biological modeling components, the socio-economic models that will be necessary to better inform fisher's choices and Council decisions are less developed. Based on experiences from around the world, the presentation also noted that adaptation is well underway but remains largely reactive, uncoordinated, and uneven across regions, communities, and sectors. There is a general lack of proactive planning for a changed future. **The key to making progress is to focus on actionable advice and locally tailored solutions.**

Curry Cunningham (UAF, SSC member) and Ian Stewart (IPHC, SSC member) provided food for thought on the challenges associated with non-stationary processes and dynamic reference points, highlighting the potential benefits, risks, and necessary considerations for managing fisheries in a changing ecosystem. **Non-stationarity is pervasive in Alaska's marine ecosystems and in biological processes including mortality, recruitment, growth and maturity/fecundity.** For example, the average recruitment or productivity of many stocks, and its variability, may change over time, either directionally or periodically as 'regime shifts', with important consequences for biological reference points. It was noted that **most reference points used in our assessments are dynamic** in the sense that they typically rely on 'regime

period averages' for population processes and parameters. A primary challenge for fisheries stock assessment is knowing when and how to adjust assumptions about the dynamics of a stock when such changes occur. It was suggested that any natural processes that affect stock dynamics should ideally be accounted for in stock assessment models for setting reference points based on unfished conditions. However, it is unclear if and how transient environmental events (e.g. heat waves), catastrophic events (e.g. oil spills, disease outbreaks), or gradual directional changes should be incorporated as drivers in models. While the occurrence of some of these events may reflect a new reality and may become more frequent, **whether or not to manage to a 'new normal' is a policy call as much as a scientific decision.** A case in point are the recent marine heatwaves that led to a period of high mortality and the collapse of Pacific cod in the Gulf of Alaska and snow crab in the Bering Sea.

Workshop discussions focused on several considerations regarding stock assessments for groundfish and crab in the Bering Sea, as well as more generally.

- A discussion about the downside of biomass reference points that are too low noted that this could result in fishing a stock too hard and could ultimately result in foregone catches. For example, if natural mortality is set too high, we would typically fish harder and could trap the stock in a low-productivity state.
- It was suggested that F-based reference points (input controls), which are less sensitive to uncertain biomass estimates and could potentially follow variations in stock size more closely, may reduce the risk of overfishing and may be more robust under non-stationarity. This would be a major change from how Bering Sea fish stocks are currently managed, but may be worth exploring as an alternative in some situations. However, the data requirements for reliably estimating fishing mortality can be very high and the approach may be impractical for many stocks. Moreover, past problems with input controls prompted the shift to annual catch limits in the first place, and it is unclear if these problems can be overcome with modern approaches.
- The time frame for defining stock productivity (average recruitment) is a key consideration for most stocks in Alaska. For Tier 3 groundfish stocks that period has been selected to start in 1977, following the 1976/77 regime shift. This puts the focus on trying to maintain the long-term average productivity, but may not reflect current conditions as average recruitment has declined over time for some stocks. **When to change the reference period is a critical question in a changing climate.** Selecting a more recent productivity period when recruitment is declining carries risks of overfishing an already declining stock and can result in a 'ratcheting' effect. At the same time, it can result in more conservative management of stocks whose productivity is increasing.
- Another challenge is the current focus on single-species assessments and reference points that may not adequately account for species interactions or the interactions between multiple stocks and multiple fishing fleets with different selectivities. The system-level cap on groundfish removals in the Bering Sea is one tool that forces explicit trade-offs among species and has been shown to provide some buffer for potential negative effects of climate change on Bering Sea fish stocks (ACLIM results).
- The workshop did not discuss changes to HCRs at this time, but reviewed preliminary ACLIM results that explored the consequences of moderate adjustments to the HCRs. Changes considered in these analyses were (1) reducing fishing mortality to 0 below $B_{25\%}$ or (2) increasing the biomass target to $B_{50\%}$. **Preliminary results suggest declines in biomass and catches of major groundfish stocks and snow crab under most warming scenarios and HCRs.** In some cases, variability associated with different climate projections was larger than differences among HCRs and climate effects tended to reduce differences among HCRs. There was little benefit from the $B_{25\%}$ threshold to biomass, but the threshold resulted in considerable losses to the fishery in some cases due to frequent fishery closures when biomass would be reduced below $B_{25\%}$.

Analysts also found that t**he effect of adjustments to the HCRs was generally much smaller than the effects of the 2 MT cap.**

During the open mic period and additional SSC discussions, participants touched on a wide range of issues relevant to the northern Bering Sea in a fishery management context. Much of the discussion centered around **improved communications with and opportunities for input from local communities, as well as the fishing industry**. The importance of identifying shared priorities and being clear on mutual expectations was noted. Participants appreciated the opportunity for input provided by the workshop and highlighted the importance of better approaches for incorporating this input into the management process. Existing barriers to communication were also noted, including the high costs of attending meetings, language barriers due to technical jargon, and in some cases the need for translators between local languages and English. Smaller panels that can travel to and hold workshops at the community level, including in more remote villages, was offered as one approach for improving engagement. It was suggested that a brief, plain language summary report from this workshop might be a useful outreach tool to invite further input and engagement, as well as to learn about local needs and concerns.

A second, related theme was improved coordination of the relevant science across agencies, universities, tribes and local communities to meet both Council objectives and local needs. Many important data gaps were identified in Sessions 1 and 2. While addressing these gaps may require new resources to not compromise data collection elsewhere, opportunities to build on existing or develop new partnerships across agencies, with local experts, and with the fishing industry were noted. While new funding sources for relevant monitoring and process studies are explored, pilot studies to identify what additional data are needed would be valuable. There is no single model for how best to conduct research in the region and different models for cooperation have been successful, whether initiated by researchers outside the region reaching out to local communities (e.g. cod tagging study) or the region identifying a need and reaching out to potential partners (e.g. halibut tagging study). Several participants highlighted the wealth of expertise that exists within the region about individual species as well as the broader ecosystem, although the pathways for bringing this information into the management process is not always clear and needs improvement. Other emerging opportunities include cooperative research with industry partners that have expanded their operations into the northern Bering Sea due to shifting fish distributions. The capacity to integrate and analyze existing and new data sources is often lacking at the local level, but increased engagement with universities could tap into underutilized capacity that may exist at some institutions, again highlighting the need for improved coordination.

The strong dependence of local communities on marine resources for food was another frequent theme throughout the workshop, highlighting the tension between local food security and commercial fishing interests as fisheries expand into the northern Bering Sea. This presents new challenges to the Council as it balances potential trade-offs among user groups that had limited or no interactions in the past.

A key focus of SSC discussions during Session 3 was on how to manage current fisheries in the face of directional changes in the ecosystem and increased uncertainty. As we consider the implications of climate change for stock dynamics and how best to incorporate observed changes into assessments, the objectives for managing fisheries in a rapidly changing environment are not always clear. Options may range from trying to preserve the existing ecosystem, with some participants arguing for maintaining the NBS ecosystem in an unfished state, to managing under the assumption that the overall productivity of the ecosystem, and the productivity and abundance of individual species, will be changing in a new environment. **Preserving the existing ecosystem may no longer be an option and the reality of changing productivity, changing distributions, and an increased likelihood of future ecological surprises need to be clearly communicated to all stakeholders and should be accounted for in management.** However, to what extent productivity or stock dynamics have already changed is unclear and work is still needed to quantitatively evaluate if and how dynamics in the recent past, and possibly in the future, may be different from current reference periods.

How to best address these uncertainties and whether to opt for more or less dynamic reference points requires a better understanding of the associated risks as well as the level of risk tolerance, which is ultimately a policy decision. However, appropriate 'on-ramps' for communicating risks to managers, or tools for managers to assess risks and respond appropriately are currently not well developed in our region. Lessons from other regions or management bodies, such as the risk framework used by the Mid-Atlantic Fishery Management Council, should be considered. **Expediting progress on these issues may require increased dialogue between the SSC and Council, as the solutions reside at the science-policy interface.**

Several participants raised the need for more flexibility in management. Some of the work on adapting to climate change, including under ACLIM, focuses on resource users adjusting or optimizing their portfolios in a changing environment. However, **under current management, the options for fishers are highly constrained and regulations may be too restrictive to allow for effective adaptation. Allowing for more flexibility should be prioritized but may require updates to current management objectives and regulations.** This will require a careful balance as some management policies (e.g. sideboards) were specifically put in place to support communities. **Providing clear information on which stocks are likely to do better or worse in a changing environment may be one approach to help fishers, where possible, build the best fishing portfolio.**

KEY TAKE-HOME MESSAGES, RECOMMENDATIONS AND NEXT STEPS

Some key messages emerged from the workshop discussions. These reflect only a partial list to be further refined in future discussions among the SSC, the Council and stakeholders.

- The 2014-2022 heat wave event(s) and concomitant ecosystem changes are potentially on a similar level as the 1978 North Pacific regime shift as pivot points in the time series of oceanographic change in the North Pacific.
- There are major gaps in our understanding of the changes occurring in the NBS, capacity to support commercial species, and expectations for future ecosystem states.
- There are major gaps in our understanding of the relative importance of the southern Chukchi Sea as seasonal habitat for EBS fish stocks.
- Non-stationarity is pervasive in Alaska's marine ecosystems and in biological processes including mortality, recruitment, growth and maturity/fecundity.
- Regular and area-wide fish and ecosystem surveys are critically important to tracking changes and supporting sustainable management. New resources are needed to support the necessary data collection in the Chukchi Sea without degrading data collections in other regions in Alaska that are also changing.
- To ensure common understanding and inclusive engagement in issues associated with extreme events affecting ecosystems and subsequent management, improved communication and coordination among agencies, industry sectors, local communities, tribal governments, academic partners, and international parties in the North Pacific are needed.

Some high-level recommendations are provided below in table format to address both scientific and management needs at either local (northern Bering Sea) or global scales, with the latter being applicable to fishery management throughout Alaska:

Key science and management recommendations (for science community and the Council)

	Science	**Management**
Local (NBS & Chukchi)	● Develop a monitoring program focused on understanding process changes in the NBS that inform current understanding of carrying capacity and expectations for future commercial fisheries. ● Develop recommendations and secure additional funding for a periodic assessment of the southern Chukchi Sea ecosystem. ● Improve overall science coordination in the region.	● Improve engagement with tribes and communities. ● Consider mechanisms for incorporating the full spatial distribution of transboundary stocks into management.
'Global'	● Re-assess the time periods that are currently used to define the productivity of crab and groundfish stocks. ● Consider alternatives to current HCRs based on available analyses. ● Increase dialogue between SSC and Council on issues that straddle the science-policy interface. ● Identify which stocks are likely to do better or worse in a changing environment to help fishers build the best fishing portfolio.	● Increase dialogue between SSC and Council on issues that straddle the science-policy interface. ● Renewed discussion on reference period determinations in light of increased periodicity of extreme events. ● Improve the use of approaches that explicitly consider risks

Recommendations for next steps

- Consider outcomes from this workshop as the Council identifies research priorities for 2023-24.
- Incorporate the recommendations from this workshop into the development of the planned Programmatic Environmental Impact Statement process to better address the impacts of climate change on the marine ecosystems and on the people dependent on those ecosystems.
- Produce a brief, plain language summary report from this workshop as a useful outreach tool to invite further input and engagement, and to learn more about local needs and concerns.
- Form a sub-group of Council and SSC members (2-3 members each) to develop a roadmap that builds a bridge from assessment and climate science to adaptive management under climate change. The roadmap should include the products and recommendations from the Climate Change Task Force, the LKTK Task Force, and the national Council Coordination Committee - Scientific Coordination Subcommittee (SCS) meeting held in August 2022. The roadmap would recommend a direction and timeline for moving forward, recognizing the urgency for action as the North Pacific expects continued change in the near future. Questions for the subgroup to consider include:
    - Is the use of more dynamic reference points a viable alternative to current management practices, given the current Council processes under the Magnuson Stevens Act? This includes consideration of when to change the time periods over which reference points are calculated for crab and groundfish stocks.
    - Could and should social or economic objectives (e.g. Maximum Economic Yield, biomass thresholds, catch stability) be incorporated into adaptive management approaches for some stocks?
    - As stock footprints expand and shift in distribution, are regional allocations of catches in the EBS and NBS appropriate and could they be dynamic enough to address temporal variability?
    - Can risk considerations be improved upon in the context of both stock assessments (ABC considerations) and management (TAC considerations).
- Plan for a February 2024 follow-up workshop that focuses on discrete aspects of the key recommendations for science and management raised at this workshop to advise the Council. In addition to the outcomes from the sub-group roadmap, the SSC may consider the following questions that emerged during this workshop:
    - What temporal and spatial scales of information are needed to track non-stationary production, shifting boundaries, and changing species interactions?
    - What baseline information is required ahead of future extreme events to be better positioned to manage fishery responses?
    - How can we better identify ecosystem bottlenecks influencing production of key commercial fish species so the limited resources are effectively focused.

Can overall as well as benthic vs. pelagic carrying capacity be reasonably assessed and tracked to inform optimum yields in an environment changing as quickly as the