Arctic Marine Biodiversity and Ecosystem Structure Data Analysis and Synthesis

Principal Investigator: Seth L. Danielson and Katrin B. Iken[1]

1 College of Fisheries and Ocean Sciences, University of Alaska Fairbanks

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Excerpt from Chukchi ecosystem painting by Klara Maisch.

Contact Information:
uaf-cmi@alaska.edu
https://www.uaf.edu/cfos/research/cmi

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Executive Summary

This project convened the "Arctic Marine Biodiversity and Ecosystem Structure Data Analysis & Synthesis" scientific workshop. The overarching goal of the workshop was to foster dialogue amongst disciplinary specialists with the intent to advance our ability to integrate scientific understanding of ecosystem dynamics and biodiversity. We helped raise awareness amongst attendees of the broad variety of data that are available to foster new synthetic analyses, and we discussed potential fruitful pathways for future field and desktop studies. Discussion time was also devoted to improving and/or creating new conceptual models of the functioning of the Chukchi Sea marine ecosystem, and to the various management agency applications and agency needs. We identified a need for outreach products that can convey information about the scientific research to residents of the Chukchi Sea coastal communities, students, the general public, and others.

The major deliverable product that was produced following the workshop is a multipage, glossy-format outreach booklet that describes objectives, methods, and recent results from a number of long-running research programs and projects, including the Arctic Marine Biodiversity Observation Network (AMBON), the Chukchi Ecosystem Observatory (CEO), the Distributed Biological Observatory (DBO), the WhaleGlider project, and the Alaska Arctic Observation and Knowledge Hub (AAOKH).

The workshop contributions and summaries in this report provide a roadmap for future priority studies that would improve our ability to monitor, manage, and understand the Arctic marine system. These include, but are not limited to:

- questions and studies that seek to better understand the balance of top-down versus bottom-up controls in the face of changing environmental conditions;
- the need to better understand seasonality and the importance and roles of different biogeographical domains across the Chukchi; and
- the need to advance our models from purely biomass-based approaches to approaches that also consider biodiversity in all of its forms, including species diversity, isotopic diversity, trophic niche structure, and functional diversity.

The workshop, which took place in the midst of the COVID-19 pandemic in October 2021, was the first hybrid remote/in-person event that most attendees had participated in since the start of the global health emergency. With lively discussion through the room during the sessions, coffee breaks and shared meals, the meeting demonstrated benefits of the resumption of in-person meetings. These benefits included connecting with colleagues on a personal level, the emergence of organic discussions that seldom arise in online format meetings, and the benefits of having early career scientists directly meet and work with more senior scientists and program managers.

1.0 Introduction

Background

The Arctic Marine Biodiversity Observation Network (AMBON) and the Chukchi Ecosystem Observatory (CEO) programs in the Chukchi Sea are efforts to build and continue multidisciplinary time series observations of an Arctic shelf to better understand change through time. The two efforts are operationally and scientifically complementary, with AMBON focused on spatially extensive open-water season, vessel-based sampling of the water column and seafloor, and CEO focused on subsurface moorings that record data year-round. This report describes results of a joint AMBON-CEO synthesis and data analysis meeting for the purpose of undertaking new data syntheses, brainstorming, refining our conceptual understanding of the system, and developing synthesis products suitable for distribution to the public and policymakers.
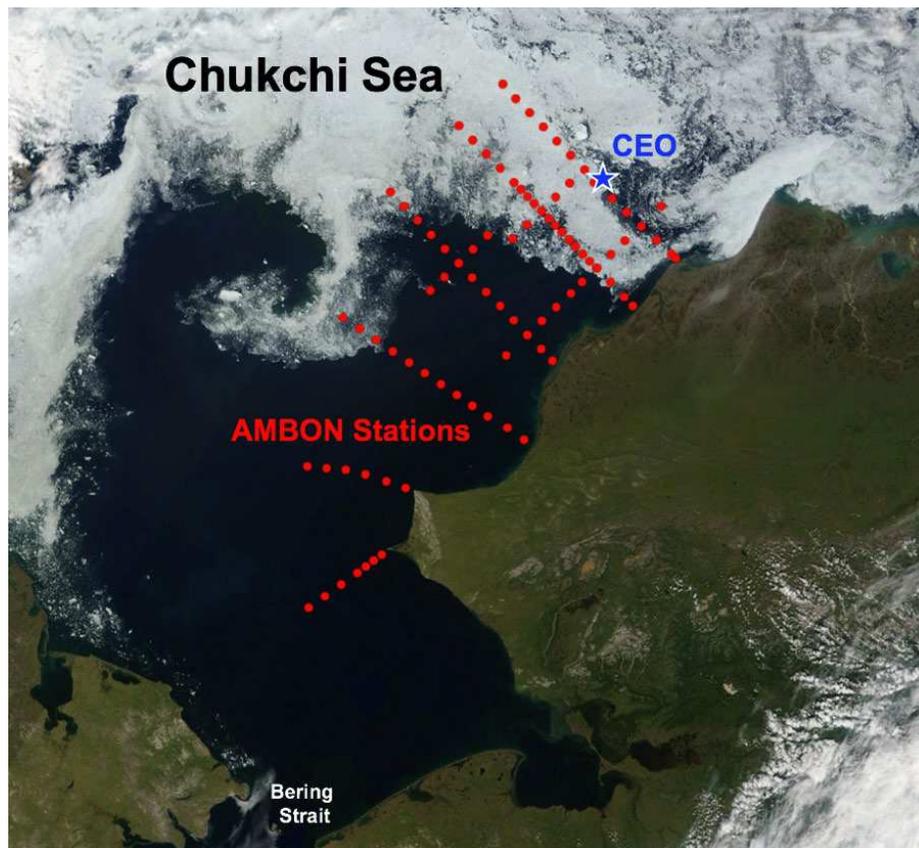
Figure 1:   True-color Satellite Image of the Chukchi Sea Showing the Location of AMBON Survey Stations (red circles) and the CEO Mooring Array (blue star)

Note: MODIS satellite image of 22 July 2012 is courtesy of NASA/Worldview.

AMBON (2015) and the CEO (2014) were both initiated near the end of the 2008–2015 period of oil exploration in the northeast Chukchi Sea (Figure 1), with the appreciation that responsible resource development in the marine environment dictates a need for comprehensive baseline studies. With information from these efforts, resource managers are better able to balance the potential impacts of proposed industrial activities with identified affected populations and habitat regions. Although oil exploration activity in the NE Chukchi Sea has been discontinued by executive order (Obama, 2016), the changing Arctic environment (e.g., Danielson et al., 2020) and potential offshore industrial activity in the Beaufort Sea suggest that increasing Chukchi vessel traffic and other industry-related activities will continue to demand the attention of marine operators, resource managers, and first responders. Hence, the AMBON and CEO programs remain relevant to environmental stewardship in the Arctic.

The goal of the Arctic Marine Biodiversity Observing Network (AMBON) project is to build an operational marine biodiversity observation network (MBON) for the US Chukchi Sea continental shelf that can also contribute to a prototype network being developed nationally. The program employs a spatially extensive, transect-based survey design to cover regions of inflow and outflow of the Chukchi Sea and different water masses, from coastal to mid-shelf. The AMBON has four main goals: (1) To close current gaps in taxonomic and spatial coverage in biodiversity observation on the Chukchi shelf, (2) to integrate with past and ongoing research programs on the US Arctic shelf into an Arctic biodiversity observation network, (3) to demonstrate at a regional level how an MBON could be developed in other regions and ecosystems, and (4) to link with appropriate programs on a pan-Arctic basis. AMBON aims to develop a sustainable model of continuous biodiversity observation with a cross-disciplinary and multitrophic level, multispecies approach including all levels of diversity from genomic to organismal to ecosystem. The AMBON project is funded through a National Ocean Partnership Program with ongoing and/or past contributions from Bureau of Ocean Energy Management (BOEM), National Oceanographic and Atmospheric Administration (NOAA), Shell Industry, the National Science Foundation (NSF), and the Office of Naval Research (ONR).

The Chukchi Ecosystem Observatory (CEO) is a cluster of subsurface moorings on the northeast side of the AMBON survey region that record with high temporal resolution throughout the year, including the under-sampled and poorly understood seasons when sea ice typically inhibits ship-based sampling. The moorings capture physical, nutrient and carbonate chemistry, particulate, microbial, phytoplankton, zooplankton, fisheries, and marine mammal data sets, thereby providing an unprecedented view into the mechanistic workings of the Chukchi shelf ecosystem. With over five years of continuous measurements, the CEO has established itself as one of the premier Arctic multidisciplinary datasets. This highly instrumented mooring's payload is unique for the Alaskan Arctic, and rare for any continental shelf. The CEO is funded by a consortium that includes agency, academic, and industry partners, including the North Pacific Research Board (NPRB) and the Alaska Ocean Observing System (AOOS), with participation by scientists from the University of Alaska Fairbanks (UAF), the University of Washington, the University of Maryland Center for Environmental Science, and Amundsen Science.

Arctic regions are expected to strongly reflect the impacts of an altered climate. The shelf region where the CEO is deployed is well situated to monitor the state of ocean acidification, changes to nutrient and carbon cycles, and how changing wind, wave, and ice affect the regional oceanography. Our datasets include biogeochemical model validation data and inform our

understanding of the marine carbon pump and shelf-basin exchanges. AMBON fills taxonomic (microbes, nano- to microplankton, benthic infauna, epibenthos, fishes, seabirds, and mammals), functional (food web structure, biological traits approach, sediment and water column characteristics), and spatial (coastal to middle shelf) gaps of other field programs by sampling at full ecosystem scale and linking to oceanographic observing systems. The AMBON efforts extend much-needed spatially explicit, coincident lower trophic and upper trophic level time series that extend across both the pelagic and benthic realms, which are essential for detecting any trends in the Arctic ecosystem. Due to the extremely high seasonal and interannual variability, and because climate changes in this system are accelerated compared to elsewhere in the nation, only long-term datasets can provide the basis to distinguish the "noise" of natural variability and regular cycles from the directional change driven by climate changes or other stressors. The Arctic is experiencing the most dramatic temperature increases of all oceans (Overland et al., 2019; Previdi et al., 2021), leading to significant alterations of marine ecosystem structure and function (Huntington et al., 2020). The importance of the Arctic Ocean to global climate and ecosystem processes and the speed at which climate changes are already occurring in the Arctic elevate the urgency for coordinated observations of Arctic marine biodiversity.

Figure 2: Illustration of the Mooring Array and Ecosystem at the CEO Site

Note: Ecosystem components and the observing platforms include: (A) Mooring array, (B) brine rejection, (C) dark winter, (D) sea ice algae bloom, (E) receding sea ice, (F) phytoplankton bloom, (G) stratification, (H) vertical gradient of nutrients and inorganic carbon, (I) sinking particulate organic matter, (J) rich benthic ecosystem, (K) foraging walrus, (L) Arctic cod, (M) storm-induced mixing, (N) senescent planktonic ecosystem, (O) research vessel Sikuliaq, and (P) glider. Reproduced from Hauri et al. (2018). Watercolor painting by Fairbanks, Alaska, artist Klara Maisch.

Communicating amongst both scientific and nontechnical audiences about biodiversity and ecosystem structure in the context of environmental change can be facilitated through use of conceptual models that capture key aspects of systems under consideration. One conceptual depiction of the Chukchi Sea ecosystem in the vicinity of the CEO mooring site (Figure 2)

schematically suggests the importance of change in time in this region, with aspects of both diurnal and seasonal fluctuations. This artist's rendering explicitly and representationally captures many important factors that together comprise the regional habitat, species assemblages, and driving forces that comprise the region's unique character. For example, Figure 2 depicts the annual cycle of dark-to-light-to-dark, and also suggests the diurnal vertical migration of zooplankton that is triggered by light illumination intensity. Turbulent mixing induced by ice keels and wind-driven waves fosters resuspension and injection of nutrients into the euphotic zone. The biological productivity and carbon cycling in the water column is a companion to benthic feeding marine mammals and rich seafloor ecosystem. From seasonality of planktonic species in the water column (Lalande et al., 2020) to spatial distributions of seabirds (Kuletz et al., 2015, 2019), fishes, benthic organisms, and microbes (Iken et al., 2019), the combination of the CEO and AMBON programs has much to offer toward further refining our understanding of the ecosystem represented in Figure 2.

Objectives

As a synthesis effort, this project did not test mechanistic hypotheses but instead applied an inquiry-based approach to improve our collective understanding of ecosystem functioning in the context of a changing climate and ocean conditions. As such, our prime objectives were to:

- Advance our understanding of the Chukchi Sea ecosystem by enabling combined analyses of summer season, station-based measurements with year-round mooring-based observations.
- Review existing conceptual models and update or develop a new conceptual model that describes the evolving ecological functioning of the Chukchi shelf.
- Identify gaps in knowledge and future research needs.

2.0 The Workshop

Participation

The major activity of this project was a multiday workshop that was held in hybrid mode in Anchorage, Alaska, 26–28 October 2021. The proposal was written prior to the COVID-19 pandemic, and at the time of the workshop vaccines were readily available, and all participants were vaccinated. This event was the first in-person gathering that most who attended the meeting had participated in following the start of the COVID health emergency. Our meeting safety protocols included mask-wearing by all participants except while eating and a guidance for participants to follow low-risk activities for the two weeks prior to the meeting. We are happy to report that no COVID cases were reported amongst participants during or just after the workshop. Twenty-four participants joined the workshop in total, with 18 in-person and 6 remotely via Zoom online. A few people joined virtually or in-person for only part of the first or last day of the workshop. Attendees included BOEM and AOOS personnel (e.g., Molly McCammon, Sheyna Wisdom, Cathy Coon, Christina Bonsell).

Figure 3: Meeting Participants

Note: (left to right) Savannah Sandy, Laura Sutton, Lee Cooper, Sue Moore, Jackie Grebmeier, Tyler Hennon, Rachel Potter, Seth Danielson, Russ Hopcroft, Catherine Lalande, Franz Mueter, Katrin Iken, Matt Galaska, and Leandra Sousa. Online participants included Claudine Hauri, Laurie Juranek, Silvana Gonzalez, Maria Kavanaugh, and Kathy Kuletz.

While the original proposal focused solely on the AMBON and CEO programs, due to the breadth of data collected by the DBO program and the tight linkages between all three, we also brought representatives from this program into the planning and participation of the workshop. In preparation for the meeting, we asked that participants consider a few topics from each person's disciplinary perspective: linking time series and spatial data; building on other recent field efforts and analyses; assessing ecosystem and biodiversity change in time; and policy and management implications and recommendations. We also asked that participants identify standard and new or underutilized data streams that could facilitate future analyses.

Approach

One goal of the workshop was to trigger future productivity in the form of papers, proposals, or outreach products. We have a few examples of student papers and theses that benefitted from the workshop (e.g., Gonzalez et al., 2023; Sandy, 2022), and ideas from the workshop were incorporated into proposals that were shortly thereafter (December 2021) submitted to the North Pacific Research Board (NPRB) Arctic Integrated Ecosystem Research Program (AIERP) call for synthesis proposals. Participants at the workshop were part of both major funded proposals of the program (one led by NOAA, one led by UAF), and those authors had the benefit of the workshop to help focus some ideas. In addition, the workshop also helped us refine ideas for outreach products, such as newly created glossy fliers that will be combined into a multipage booklet describing a number of long-running research programs that study ecosystems, biodiversity, and the governing processes.

Following the in-depth workshop discussions of the above focused topics on Day 1 and the breakout brainstorming sessions of Day 2, we were able to then take a step back on Day 3 and consider the whole of the content previously presented, which included discussion of mechanistic effects on system, biology, and temporal effects. From a systems point of view, we reframed our discussion from the vantage point of biophysical interactions that fall into categories of (1) macroecology and its regulation, (2) environmental drivers and mechanistic regulation pathways, and (3) factors that relate (1) and (2). Macroecology regulation includes factors such as the food demands and prey availability that feed into energetics considerations; species-species interactions; behavioral considerations; static habitats; non-static habitats; population dynamics; and a variety of spatial-temporal considerations. From a mechanistic regulation standpoint, important factors include water temperature and salinity; light; nutrient standing stock and fluxes; advection; wind effects; water masses; stratification and mixing; and ice. Bridging mechanistic controls and macroecology, we anticipate that biological rates, the environmental setting, and the passage of time are all important. Specific controls include, pelagic productivity, benthic productivity, the marine carbon pump (including export processes), weather and climate, and how these change with time and contribute to the habitat conditions.

Topics of Presentations and Discussion

Each attendee provided one slide that identified a topic (i.e., paper) that they would be notionally interested in contributing to or leading, along with a few bullets of main underlying ideas that could form the basis of a rough outline (see Appendix B). Each presentation was formed as an elevator pitch for a cross-disciplinary analysis. We reviewed these presentations for common ideas and then as a group selected a few efforts to discuss in greater detail, listed below:

- Spatial-temporal patterns of pelagic components of the Pacific-Arctic ecosystem
- The role of sea ice presence, draft, and leads
- Pacific-Arctic ecosystem state of the union and trends
- Bottom-up vs. top-down controls on Pacific-Arctic benthic communities
- Changes in remote and local nutrient supply, and lower trophic level consequences
- The impact of primary productivity and transport on seabird and marine mammal prey availability
- Using eDNA to quantify impacts of climate change to biodiversity
- Downstream implications of Arctic-bound nutrients through Bering Strait

- Bottom-up vs. top-down biological controls
- Functional trait space: an ecosystem perspective
- Seasonal differences in under-ice aggregations of zooplankton and fish, and water mass association
- Late-season productivity and how it contrasts with earlier seasons
- Time series trophic interactions over varying space and time scales
- Changing physical habitats in the Pacific Arctic
- Long-term changes in summer zooplankton communities
- Mechanisms impacting seabirds during Pacific-Arctic heat waves
- Biogeochemical cycles at the CEO
- Acoustic detections of marine mammals relative to ice extent and water temperature

Following the presentations and associated discussions, we spent time on Day 2 of the workshop in a combination of plenary and break-out sessions designed to dive a bit deeper into a few key topics. The first of these focused on potential foci for future analyses and analytical approaches that might be fruitful, and the discussions identified the following potential pathways:

- Drivers, biological considerations, temporal & spatial variations
- Beyond biomass analyses: change over time of diversity in species, isotopes, trophic niche, functional diversity, diversity evenness
- Machine learning for data processing and analysis tasks
- Trophic interactions through time
- Marine mammal responses to altered physical habitat
- Defining eco-regions
- The need for better and multiple "box models," including for the benthos
- Source populations of zooplankton

3.0 Conceptual Models

Day 2 of the workshop also devoted significant time to breakout discussion sessions in which participants were encouraged to collaboratively develop one or more conceptual models that could help improve our understanding of the Chukchi marine system.
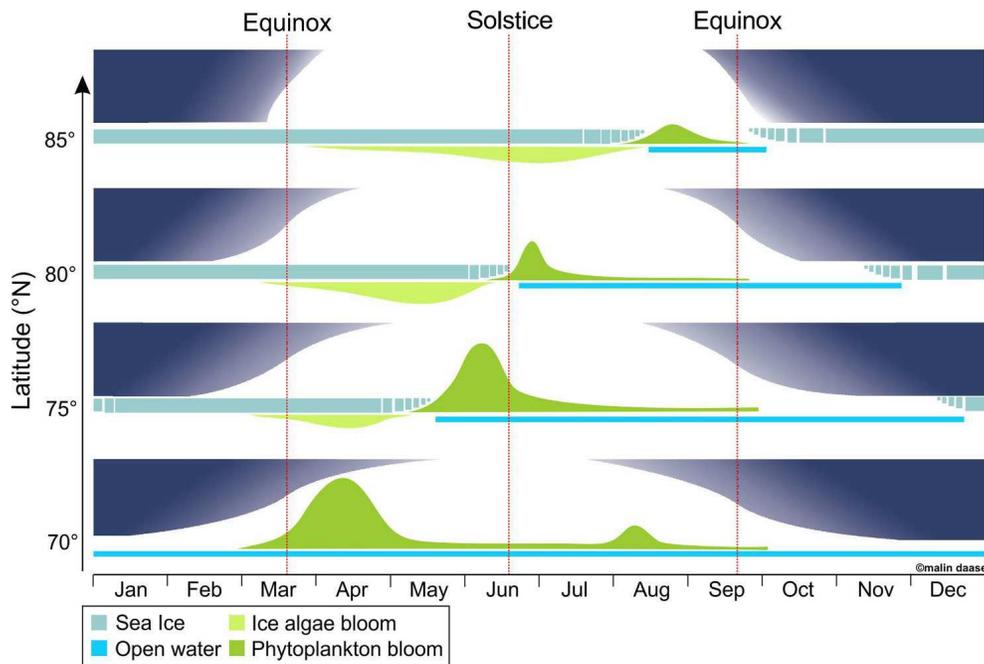
**Figure 4:   Example Conceptual Model of Wassmann et al. (2020)**

Note: Shows the effect of latitudinal gradients on the timing and duration of sea ice breakup/freeze-up and open-water conditions, and the magnitude and timing of irradiance, phytoplankton, and ice algae blooms

Naturally, a good conceptual model does not try to represent the whole of reality (if that is the goal, just go visit the Chukchi Sea!). Instead, the best conceptual models often clearly identify a component of a system that would benefit from an accessible presentation and are able to frame the important pieces simply yet adequately. Some conceptual models attempt to explain a single idea; others provide insight to contrasting scenarios; and yet other conceptual models allow the user to test hypotheses or even assess the outcome of newly formed questions beyond the scope of the originator's vision. For a recent review of conceptual models that target the Arctic Ocean system, see Wassmann et al. (2020). A number of examples of conceptual models were shown to the group (focused primarily—but not exclusively—on various Arctic scenarios) as a means to engender some discussion about potential improvements, shortcomings in existing models, alternate approaches, or fully new models with fresh applications.

Factors considered (by the workshop attendees) important to capture for improving existing models or creating new conceptual models include:

- Adapting existing models to Pacific Arctic subregions
- Advective, light cycles, ice, water masses, nutrient levels

- Seasonality
- Present vs. past and future ecosystem states
- Simple, with differences between scenarios readily apparent
- Timing match/mismatch between ecosystem components (e.g., predatory/prey interactions, timing of spring bloom and zooplankton consumers)
- Atmospheric forcing: advection & mixing
- Inshore vs. offshore
- Some approaches require new analyses
- Designing models for hypothesis testing
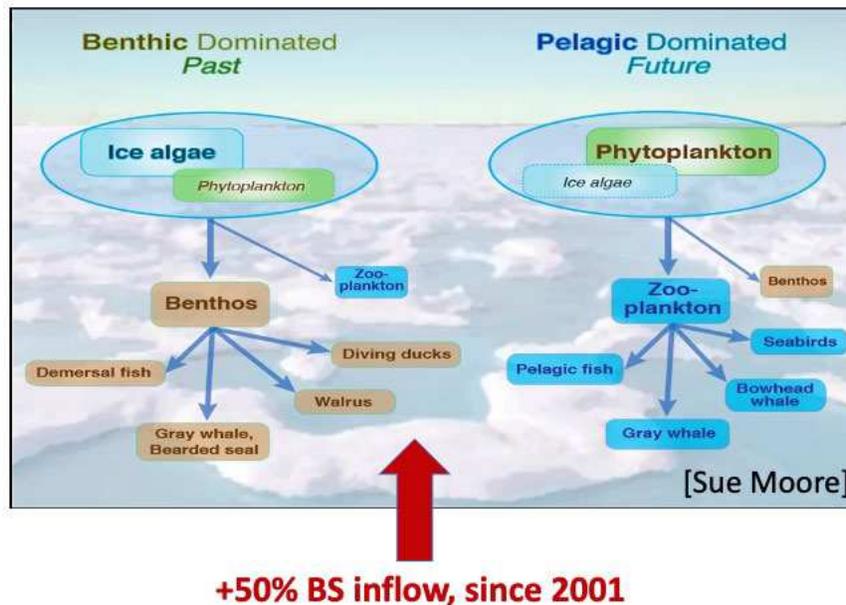
Figure 5: Starting Point Conceptual Model of the Chukchi Sea Ecosystem under Present and Future Climate Scenarios

Note: Provided by Sue Moore

Pathways to improved conceptual models

Aggregate suggestions for improving conceptual models of the Chukchi Sea ecosystem include the following points.

- Regional parsing of Chukchi Sea
  - 4 regions: southern, northeastern, inshore, offshore
  - Boundaries: north Bering, northern Chukchi shelf break
  - Potential data streams (for each region)
    - SeaScapes (multiparameter identification ocean habitat types of water mass and persistent biogeochemical features using model and satellite-derived measurements)
    - Acoustics
    - Satellite information

- ▪ Moorings
- ▪ Sampling
- o Potential data streams for different ecosystem components
  - ▪ Phytoplankton
  - ▪ Zooplankton
  - ▪ Seabirds
  - ▪ Fish
  - ▪ Benthos
- o Analysis of each model "box" and how it changes over time, and how changes in one box might be related to another box
- o Decadally averaged analysis to reduce "noise"?

- • Regional analysis: extend beyond the focal DBO lines using all available data
  - o Coarse comparison of relationships between boxes in the model
  - o Seasonal evolution of each region: identify gaps in data (there will be many)
  - o Include acoustic data

- • Identify where the model is being applied geographically and temporally
  - o The unique regions of Barrow Canyon and Hanna Shoal

- • Time lags of advection, sea ice extent
  - o Analyze "downstream" effects
  - o Apply analysis to other datasets (e.g., seabirds)

- • Modify the model to incorporate entire Arctic system

- • Identify source populations of important species

- • Make the benthos box more closely related to zooplankton instead of being separate

- • Use larval ecology to inform connections

Emerging Themes for Future Research

Reconvening in plenary, we identified a number of emerging themes and research questions that may be important to follow up on in the future. Some of the proposed ideas will require a significant analysis effort that is well beyond the scope of this project. The identified topics include the following:

- • We have in hand now a variety of conceptual models describing how the system has changed (or will change). How well can we support the conceptual models with data?

- • What is the role of food quality?

- • What is the role of predation?

- • How should conceptual models include biodiversity?
  - o We could try to expand from models based on biomass into models that include:
    - ▪ Species diversity
    - ▪ Isotopic diversity
    - ▪ Trophic niche structure
    - ▪ Functional diversity
    - ▪ Diversity evenness vs. dominant species
    - ▪ How these all change over time

- How should our conceptual models address important regional differences?
- What is the role of top-down versus bottom-up changes in the Chukchi Sea marine ecosystem in light of the massive recently observed environmental changes and the associated changes in species distributions?
- Revisit shifts between a benthic- and pelagic-dominated system. Can we support the conceptual model with real data?
  - Model built on biomass, not diversity
  - Food *quality* might be a factor; smaller size plankton rather than fewer plankton?
  - Update model to include diversity?
  - Model may miss advection, timing
  - Discussion of phytoplankton and zooplankton size analysis
  - Consider: predation pressure, harmful algal blooms (HABs)
- SeaScapes may be used as a basis for conceptual modeling
  - Relating drivers to resolved responses will be important
  - Some satellite data limitations when sun angle is low

During the workshop, participant Dr. S. Gonzalez presented two draft conceptual models (Figure 6), which were subsequently refined and then published (Figure 7; Gonzalez et al., 2023). This conceptual model incorporates aspects of the biological realm (polar cod, ice algae, phytoplankton) in addition to the physical environment year-round based on CEO data, and focuses on a data-informed understanding of biological and environmental differences between years with late season vs. early season ice retreat.
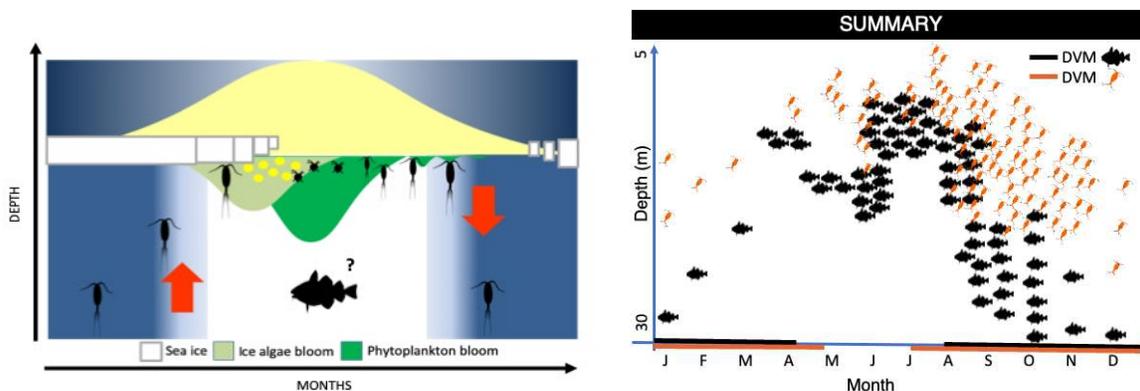
Figure 6: Draft Conceptual Model Schematics Provided by S. Gonzalez at the Workshop
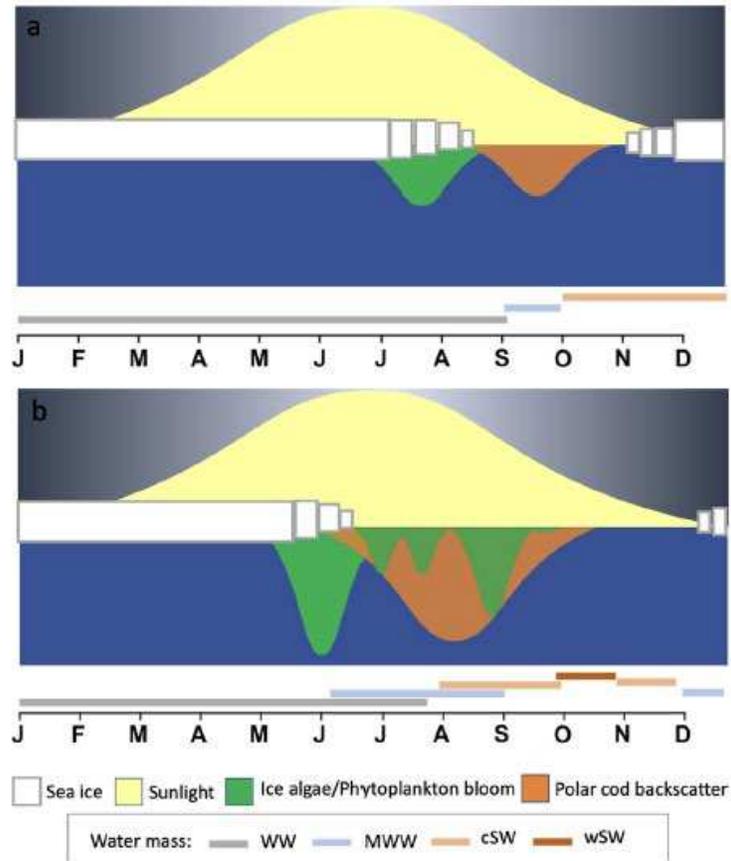
Figure 7: Published Conceptual Model of the NE Chukchi Sea Annual Cycle of Water Masses, Light, Sea ice, Phytoplankton, and Polar Cod in Contrasting Cool (a) and Warm (b) Years

Note: Reprinted from Gonzalez et al. (2023).

4.0 Research and Resource Management Needs

Research Needs

A lively discussion about research needs is summarized below. A few comments about the importance of the first bullet point are required for context, given the changing geopolitical relationships between 2021 and 2023.

The global geopolitical situation has evolved even in the last two years as a result of the COVID-19 pandemic and other factors, such as the Russian war in Ukraine. Science can be one of those bridging components of society that maintain human connections even in the face of political turmoil. Although our federal agency partners may not be able to join in cross-border scientific collaboration during this period of Russian isolationism, as academic scientists we should do our part to ensure that scientific advances and data collections do not suffer due to political factors that may change with elections and political upheaval. In context of the 12 June 2022 guidance on scientific collaboration from the White House, we note that federal employees and agencies are disallowed from cross-border collaboration and transfer of research funds but that: "Non-government institutions should make their own determinations regarding how to proceed with contact and collaboration between the United States and Russian scientific communities, in furtherance of an open exchange of ideas within the international science and technology community." The need for the comments below made at the meeting with respect to research needs and cross-border engagements have not diminished, but the landscape for ethical engagements even at scientific levels has unquestionably changed.

- Russian–US data for the Chukchi Sea
  - Reengage and collaborate with Russian scientists
- There is a lack of surveys and sampling for larger fish in the Chukchi
- We should assemble an understanding of high-resolution seasonal patterns (involving the CEO data, perhaps), particularly with regard to the lower biological trophic levels
- Need for under-ice sampling of fish and plankton, nutrients and chemistry
- Undertake a cost-benefit analysis for improving/extending existing mooring arrays
  - Strategizing about places to add ecosystem observatories/components to help fill in gaps between existing ones
  - Need to identify locations of greatest need
  - Must consider optimization of mooring turnaround logistics

Resource Management Needs

To gain insight into the needs of resource managers (some agency personnel stopped by and connected by Zoom on Day 3 of the workshop), we heard from participants and management agency personnel about the need for a variety of specific information products and issues that require additional scientific data.

There was a general appreciation that management information needs are changing between industry, conservation, subsistence interests as fishery stocks move north. Resource managers and others need to nimbly shift boundaries as habitats change. There is potential utility of dashboards and user groups; many information products can fill multiple needs. There will very

likely need to be more information from regions that are expected to be most impacted by industry in the coming years (shipping, oil and gas development, fishing, etc.).

Discussion in this section of the workshop touched on the following points:

- Areas of concern include:
  - Vessel traffic, including shipping
  - Fishery bycatch
  - Marine birds and mammals
    - Migration routes and timing
    - Increasing anthropogenic noise
    - Ship strikes
  - Sensitive areas
    - Biologically sensitive
    - Susceptible to oil spills
- Increase sampling in the Chukchi Sea
  - Regional subdivisions needed?
  - Modeling approach
  - Determine sampling approaches, e.g.:
    - Transect vs. grid
    - Sampling many stations in fewer years or fewer stations every year
- Forecasting
  - Stakeholders are interested in knowing what is going to happen
  - Track multiple stressors
  - Provide timelines ("on what timescale is this going to be a problem?")
- Habitat mapping
  - Life-stage specific
  - Timing specific—seasonal (e.g., bowhead whale migration)
  - Invasive species
  - Species of interest to industry
  - Need a dynamic approach to management as habitats change (e.g., borealization)
- Real-time monitoring is still very much an emerging activity in the Arctic but has potential to be operationally useful
  - Cabled arrays to get real-time measurements
  - Real-time monitoring for potential entanglements (e.g., whales)
  - Monitoring of seabirds is detectable with underwater acoustics
  - Real-time monitoring to determine shifts in habitats, hotspots, etc.
  - Utilizing frequent sampling of small stations/lines (e.g., DBO) in concert with larger spatial grids (AMBON) to capture spatial shifts
  - Disposable vs. retrievable equipment—reduce plastic pollution
- Agencies seek peer-reviewed articles to identify management needs
  - An up-to-date bibliography of the region would be useful
    - Include international papers
  - Visualizing spatial data across the ecosystem
- Management needs as a topic is a much broader conversation than just one agency's needs

- BOEM, USGC, NOAA, USFWS, etc.
- Importance of partnerships as focus moves away from oil/gas and toward renewable energies
  - Identifying key habitats (e.g., deep-sea sponges and corals) in areas with potential for critical minerals (e.g., the Aleutians)
  - Tidal energy
  - Economic impacts/benefits to Arctic communities
- Focus on how to keep information flowing in

5.0 Outreach

Outreach Goals and Approach

During Day 3 of the workshop, participants discussed options for getting scientific results back to the various communities who have interest in the work done by these programs. These include but are not limited to residents of the coastal communities near and in the study area, marine mammal co-management groups, the general public, fishers, grade school teachers and K–12 students who are occasionally visited by project scientists.

Comments during this discussion included the following:

- Pictures and simple charts/conceptual models may be better for a general audience, rather than complicated data graphs.
- How about an "Eyes and Ears on the CEO" type of pamphlet? It is such a special spot.
- Fliers could help educate the public on what the many acronyms represent.
- Help people understand why scientists do what they do—elevating the discussion beyond the nuts and bolts of a single project helps identify the big picture.
- There should be a map, and should have pictures because community words for animals, etc., might be different.
- Relate to food/food security if possible.
- The National Parks "state of change" fliers are well received.
- Original art and minimal text; less wordy is better.
- This approach could lend itself to a website where you could hover over things in the art to get more information.
- Make sure people are included in ecosystem representation—local observations; Indigenous peoples consider themselves to be a part of the ecosystem.
- Sidebars to talk about methods with some level of detail.
- Need for two products? One that is simplified and one with a little more research for those that are curious about learning more.
- Would an ecosystem working group be valuable?

Outreach Booklet

In response to the above comments, the group decided that a set of glossy pamphlets or even a small booklet would be a useful outreach tool. We envision that such booklets would be valuable for graduate student recruiting efforts at national and regional scientific meetings, and would also be a good way for funding-agency personnel to keep tabs on high-level objectives and results coming from these programs. In addition to the three lead projects (AMBON, CEO, DBO), we have also invited participation by the Alaska Ocean Observing System (AOOS)–funded WhaleGlider project in the Chukchi Sea, the Bowhead Whale foraging project (funded by BOEM) that is run out of Utqiagvik, NOAA's EcoFOCI program, and the coastal observers program Alaska Arctic Observatory and Knowledge Hub (AAOKH).

The booklet format is now largely in place, although not all projects have yet compiled their contributions. The draft booklet pages are shown below.

Figures 8-16 (below): **Cover Page, Project Pages and Back Page of Outreach Booklet**
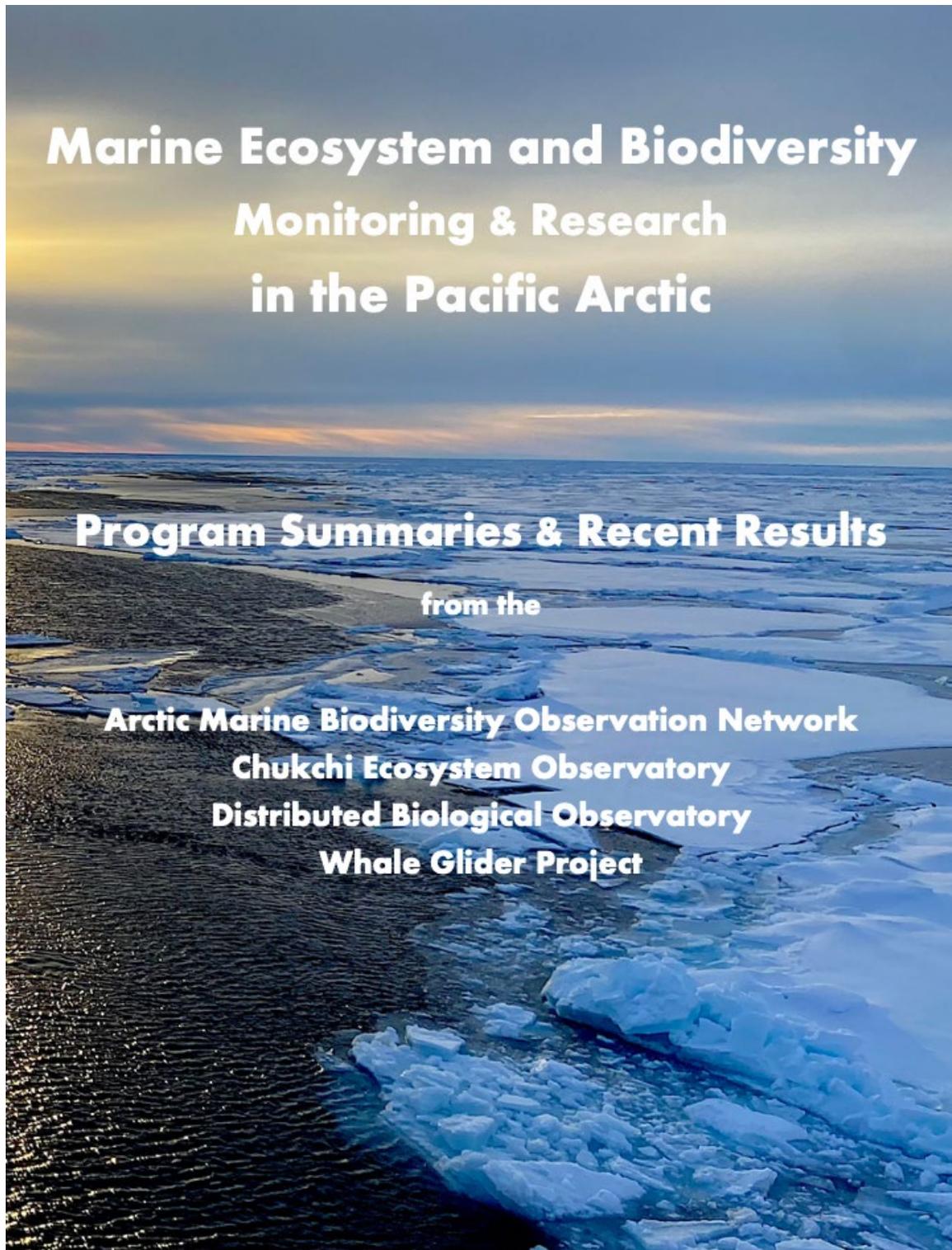
Arctic Marine Biodiversity Observation Network

AMBON is a multidisciplinary program that monitors marine biodiversity of the Chukchi Sea shelf, from microbes to whales.

Combining ship-based measurements at many stations with focused data from a single year-round mooring and coastal observer records, **AMBON** assesses biodiversity in relation to environmental conditions.
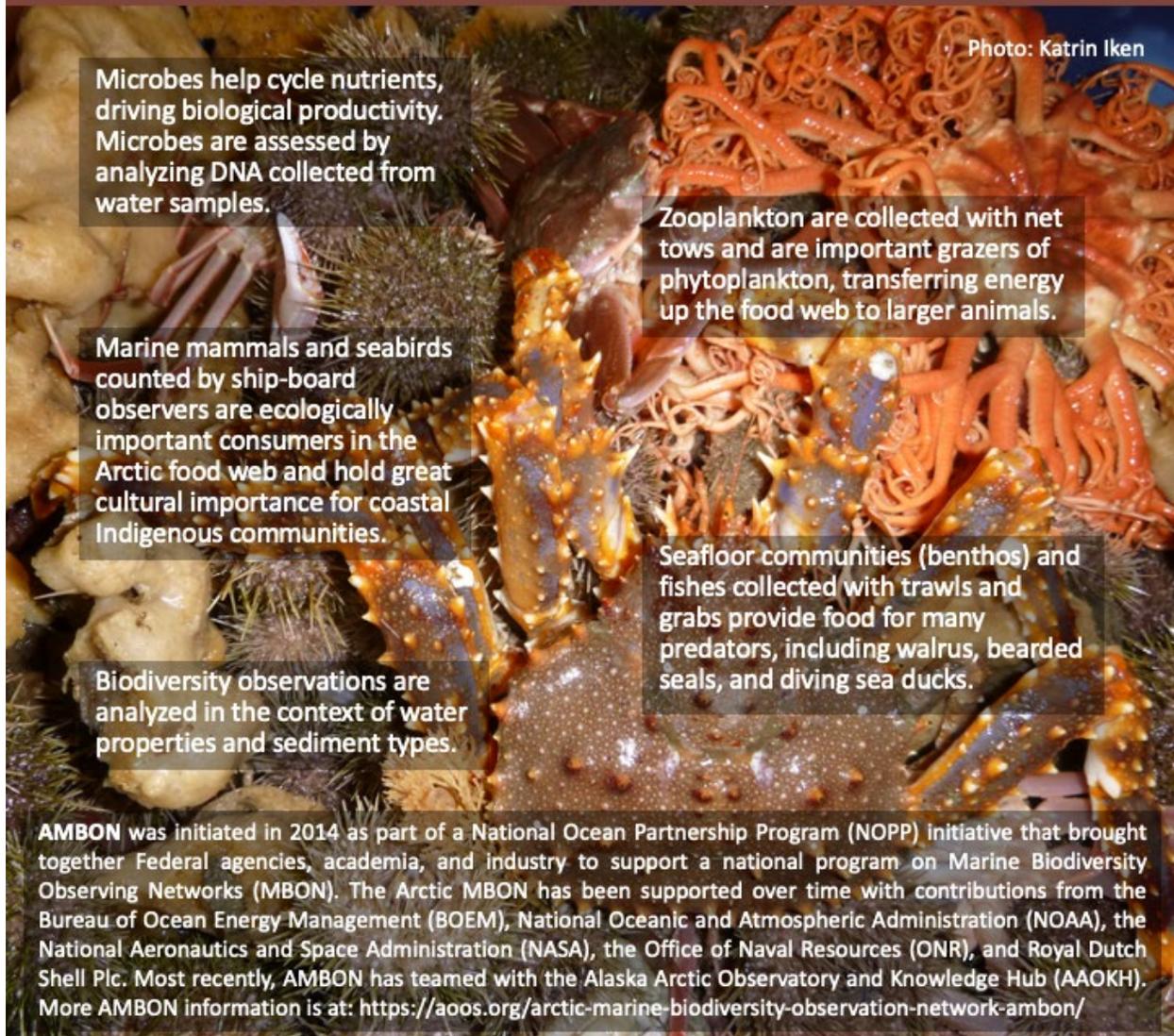
Photo: Katrin Iken

Microbes help cycle nutrients, driving biological productivity. Microbes are assessed by analyzing DNA collected from water samples.

Zooplankton are collected with net tows and are important grazers of phytoplankton, transferring energy up the food web to larger animals.

Marine mammals and seabirds counted by ship-board observers are ecologically important consumers in the Arctic food web and hold great cultural importance for coastal Indigenous communities.

Seafloor communities (benthos) and fishes collected with trawls and grabs provide food for many predators, including walrus, bearded seals, and diving sea ducks.

Biodiversity observations are analyzed in the context of water properties and sediment types.

AMBON was initiated in 2014 as part of a National Ocean Partnership Program (NOPP) initiative that brought together Federal agencies, academia, and industry to support a national program on Marine Biodiversity Observing Networks (MBON). The Arctic MBON has been supported over time with contributions from the Bureau of Ocean Energy Management (BOEM), National Oceanic and Atmospheric Administration (NOAA), the National Aeronautics and Space Administration (NASA), the Office of Naval Resources (ONR), and Royal Dutch Shell Plc. Most recently, AMBON has teamed with the Alaska Arctic Observatory and Knowledge Hub (AAOKH). More AMBON information is at: https://aoos.org/arctic-marine-biodiversity-observation-network-ambon/

Biodiversity

Biodiversity describes the number of different species, their variety, and their locations within an ecosystem.

Ecosystems with high biodiversity are often also biologically productive.

High biodiversity can foster ecosystem stability because different species are differently affected by habitat changes and interactions with other species.
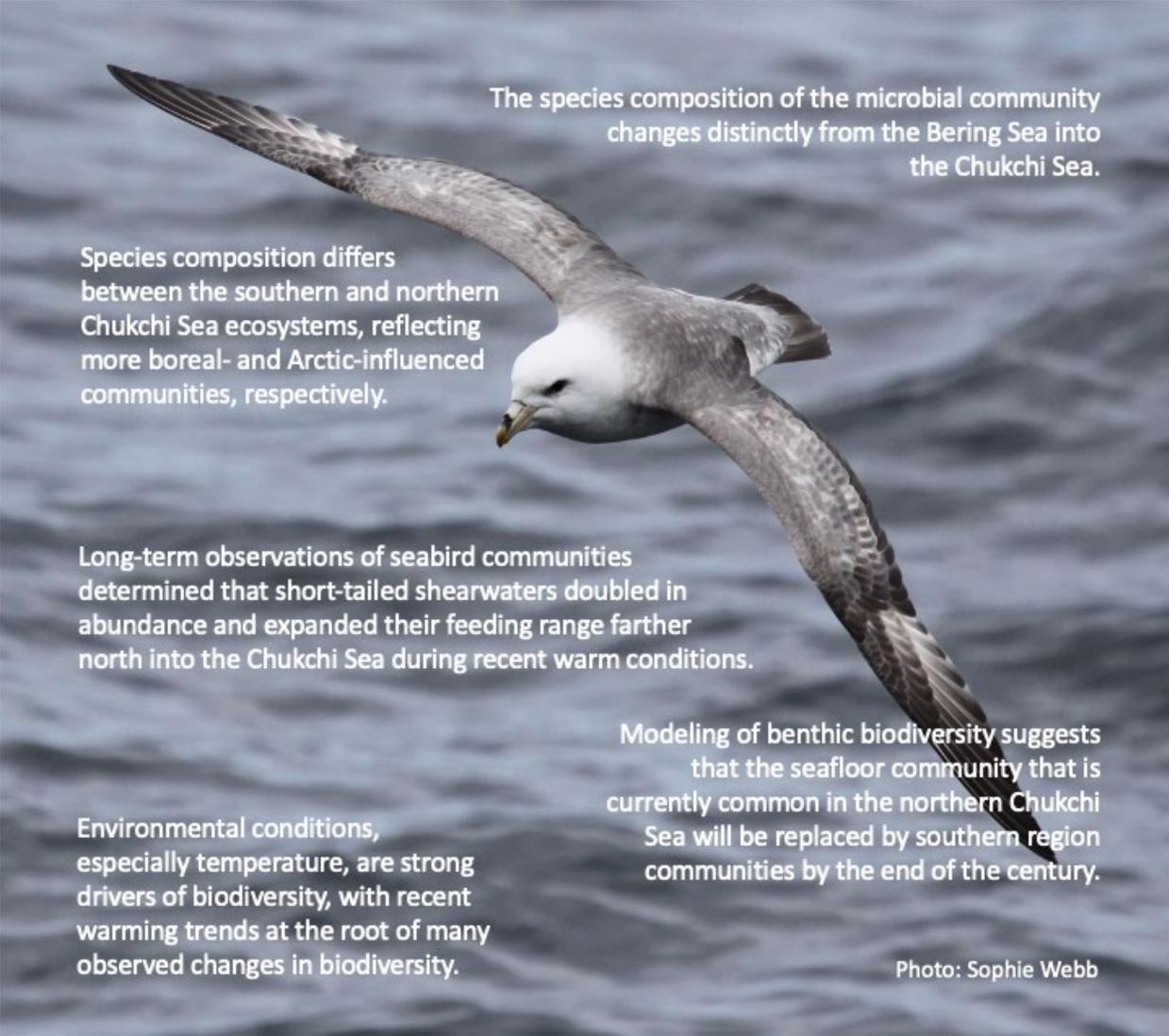
The species composition of the microbial community changes distinctly from the Bering Sea into the Chukchi Sea.

Species composition differs between the southern and northern Chukchi Sea ecosystems, reflecting more boreal- and Arctic-influenced communities, respectively.

Long-term observations of seabird communities determined that short-tailed shearwaters doubled in abundance and expanded their feeding range farther north into the Chukchi Sea during recent warm conditions.

Modeling of benthic biodiversity suggests that the seafloor community that is currently common in the northern Chukchi Sea will be replaced by southern region communities by the end of the century.

Environmental conditions, especially temperature, are strong drivers of biodiversity, with recent warming trends at the root of many observed changes in biodiversity.

Photo: Sophie Webb

Chukchi Ecosystem Observatory

The **CEO** is a cluster of oceanographic moorings that monitor the status and functioning of the Chukchi continental shelf ecosystem.

Moorings collect year-round measurements of the physical and chemical environments, plankton, fish, and marine mammals.

CEO measurements provide insights to **ecosystem dynamics** of this Arctic shelf.

Photo: Roger Topp

Physical measurements characterize the temperature, salinity, ice draft, waves, ocean currents and light environments.

Chemical measurements assess oxygen and nutrient concentrations and the state of ocean acidification.

Acoustic recordings capture sounds made by marine mammals, ships, ice, wind and rain.

Acoustic pinger measurements characterize ice draft and the location and timing of fish and zooplankton.

A time lapse camera takes photographs of animals on and near the seafloor.

A time series sediment trap captures plankton and other biogenic material that settles onto the seafloor.

Ecosystem Dynamics

Ecosystem Dynamics are the numerous linkages between populations of different species and the environment, and how they change together through time.

Scientists study ecosystem dynamics in order to better understand and anticipate the ecological consequences of changing ocean conditions.

Photo: Seth Danielson

Key environmental controls of the Chukchi Sea food web include sea ice cover, ocean temperature, nutrient concentrations, and light.

Inter-species interactions are mediated in part by temperature. As ocean waters warm, subarctic species move northward, causing overlap in the populations of subarctic and arctic species.

Sustained organic matter deposition near the CEO mooring site feeds a thriving seafloor community, which in turn provides rich feeding habitat for seals, walrus and whales.

Winter months bring cold conditions to which sub-Arctic species are not adapted, but even during this time Arctic plankton, fish and seals continue a daily cycling pattern of movement.

Walrus and bearded seals may be partitioning the use of the habitat between species based on the presence or absence of sea ice.

Distributed Biological Observatory

The **DBO** program brings together scientists from many nations who conduct time series sampling at fixed stations. The resulting aggregated data together comprise a Pacific Arctic "change detection array".

Monitoring with repeat sampling reveals biological consequences of changing environmental conditions.

Primary DBO data collections include:

- Seawater temperature, salinity, stratification and velocity.
- Nutrients, chlorophyll a, dissolved and particulate carbon, and optical properties of the seawater.
- Phytoplankton, zooplankton and benthic species abundance and biomass.
- Marine mammal and seabird surveys.

Additional measurements are made from satellites, moorings, underwater gliders, cameras, and harmful algal bloom surveys.

Red boxes outline the DBO sampling sites, which are occupied by national and international scientists under a shared data plan.

Each DBO site exhibits distinct productivity, biodiversity, and changes through time.
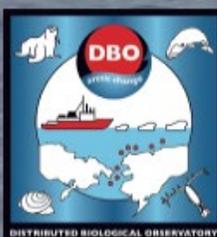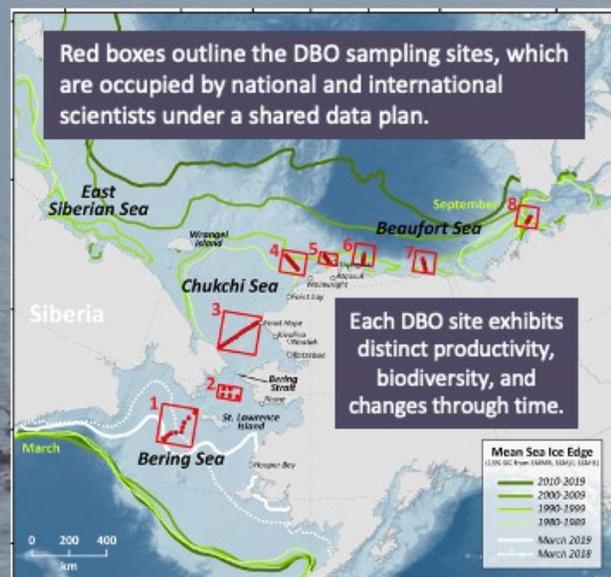
The **DBO** project was established in 2010 with support from the US National Science Foundation and the National Oceanic and Atmospheric Administration. Additional science support is provided by the US Fish & Wildlife Service, the National Aeronautics and Space Administration, the Bureau of Ocean Energy Management, and the North Pacific Research Board, and with ongoing collaboration through the Arctic Marine Biodiversity Observation Network and Chukchi Ecosystem Observatory. International DBO collaboration occurs through members of the Pacific Arctic Group, including continued development a pan-Arctic network.

Information on the **DBO** is available at: https://dbo.cbl/umces.edu

Detection of Change

The DBO, AMBON and CEO programs collect time series observations in the Pacific Arctic to document changing environmental conditions and how such changes impact key species and ecosystem structure.

Since 1922, Chukchi Sea water temperatures have increased by about 2.5 °F (1.4 ° C) in summer and fall.

The rate of ocean warming since 1990 has been much faster than in the years before 1990.

Warmer ocean temperatures cause later sea ice formation in fall and earlier sea ice retreat in spring.

A longer duration of open water conditions extends the seasonal duration of biological productivity.

Decreasing sea ice allows increased levels of solar irradiance into the ocean, which induces greater phytoplankton productivity and in turn results in elevated carbon delivery to the sediments

In the southeast Chukchi Sea, increasing benthic (seafloor) biomass is dominated by bivalves, which have benefitted from the increased phytoplankton production.

Warmer ocean temperatures have allowed subarctic fishes and marine mammals to expand foraging ranges northward.

Consequences of new species in the Arctic marine food web will emerge in time.

WhaleGlider

Since 2013, an underwater robot has been 'flying' in the Chukchi Sea each summer, from the Bering Strait to Utqiagvik, Alaska. The glider collects environmental data while also listening for marine mammals.

Monitoring with repeat sampling has revealed changes in the ocean habitat and the species living there.

Every summer the glider surveys from south to north on a zig-zag track, covering different ocean environments.

The glider collects:
- Seawater temperature, salinity, chlorophyll a, turbidity (water clarity), and water speed and direction data.
- Marine mammal acoustic detections.
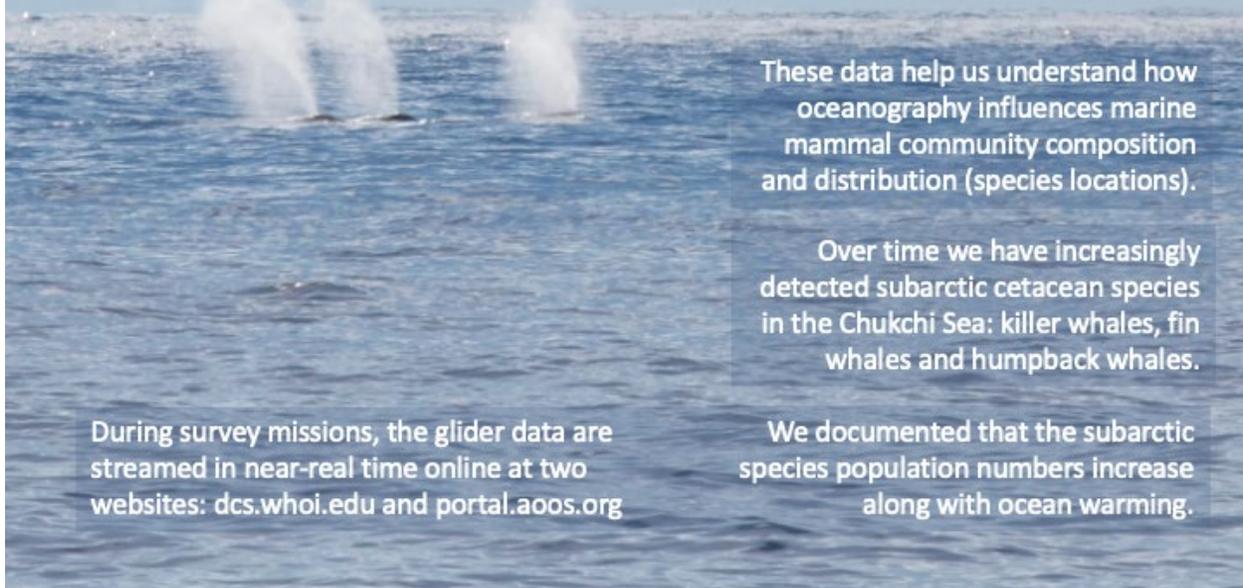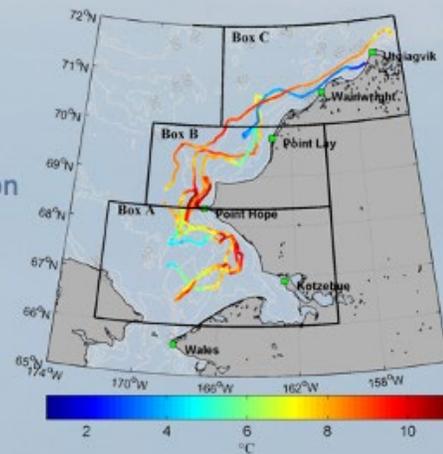
These data help us understand how oceanography influences marine mammal community composition and distribution (species locations).

Over time we have increasingly detected subarctic cetacean species in the Chukchi Sea: killer whales, fin whales and humpback whales.

During survey missions, the glider data are streamed in near-real time online at two websites: dcs.whoi.edu and portal.aoos.org

We documented that the subarctic species population numbers increase along with ocean warming.

Why study biodiversity and ecosystem dynamics?

What ecosystem changes are occurring in the northern Bering and Chukchi seas?

How do environmental conditions cause variations in marine animal populations?

Seawater warming and declining sea ice cover are impacting the ecosystem, from prey in the water and sediments to marine mammal and seabird consumers. Food security, harmful algal blooms, and ocean acidification are impacted by changing environmental conditions that influence the health of the marine ecosystem.

Scientists use long-term monitoring studies to detect and track changing environmental conditions and biodiversity. To build a rich scientific understanding, the programs described in this pamphlet use a combination of complementary approaches for addressing the above questions. For example, moorings provide data from one site through the whole year, while research vessels visit many stations, but only during the open water season. Observations and sample collections made by coastal community residents are key for a holistic view of the ecosystem that spans both nearshore and offshore regions.

UAF COLLEGE OF FISHERIES AND OCEAN SCIENCES

University of Alaska Fairbanks

6.0 Acknowledgments

7.0 References

Danielson, S.L., Ahkinga, O., Ashjian, C., Basyuk, E., Cooper, L.W., Eisner, L., Farley, E., Iken, K.B., Grebmeier, J.M., Juranek, L., Khen, G., et al. 2020. Manifestation and consequences of warming and altered heat fluxes over the Bering and Chukchi Sea continental shelves. Deep Sea Research Part II: Topical Studies in Oceanography, 177, p. 104781.

Gonzalez, S., Horne, J.K., Danielson, S.L., Lopez, G., and Segura, A.M. 2023. Temporal dynamics and environmental drivers of polar cod (*Boreogadus saida*) densities in the northeast Chukchi Sea. Polar Biology, 46(6), pp. 573-588.

Hauri, C., Danielson, S., McDonnell, A.M.P., Hopcroft, R.R., Winsor, P., Shipton, P., Leland, C., Stafford, K.M., Horne, J.K., Cooper, L.W., Grebmeier, J.M., Mahoney, A.R., Maisch, K., McCammon, M., Statscewich, H., Sybrandy, A., and Weingartner, T. 2018. From sea ice to seals: A moored marine ecosystem observatory in the Arctic. *Ocean Science* 14, pp. 1423-1433.

Huntington, H.P., Danielson, S.L., Wiese, F.K., Baker, M., Boveng, P., Citta, J.J., De Robertis, A., Dickson, D.M.S., Farley, E., George, J.C., Iken, K., Kimmel, D.G., Kuletz, K., Ladd, C., Levine, R., Quakenbush, L., Stabeno, P., Stafford, K.M., Stockwell, D., and Wilson, C. 2020. Evidence suggests potential transformation of the Pacific Arctic ecosystem is underway. *Nature Climate Change* 10(4), pp. 342-348.

Iken, K., Mueter, F.J., Grebmeier, J.M., Cooper, L.W., Danielson, S.L., and Bluhm, B.A. 2019. Developing an observational design for epibenthos and fish assemblages in the Chukchi Sea. Deep-Sea Research II, 162, pp. 180-190.

Kuletz, K.J., Cushing, D.A., Osnas, E.E., Labunski, E.A., and A.E. Gall. 2019. Representation of the Pacific Arctic seabird community within the Distributed Biological Observatory array, 2007–2015. Deep Sea Research II, 162, pp. 191-210. https://doi.org/10.1016/j.dsr2.2019.04.001

Kuletz, K.J., Ferguson, M.C, Hurley, B., Gall, A.E., Labunski, E.A., and Morgan, T.C. 2015. Seasonal spatial patterns in seabird and marine mammal distribution in the eastern Chukchi and western Beaufort seas: Identifying biologically important pelagic areas. Progress in Oceanography 136, pp. 175-200.

Lalande, C., Grebmeier, J.M., Hopcroft, R.R., and Danielson, S.L. 2020. Annual cycle of export fluxes of biogenic matter near Hanna Shoal in the northeast Chukchi Sea. Deep Sea Research II: Topical Studies in Oceanography, 177, p. 104730

Obama, 2016. Memorandum on Withdrawal of Certain Portions of the United States Arctic Outer Continental Shelf From Mineral Leasing, December 20, 2016. Administration of Barak Obama.

Overland, J., Dunlea, E., Box, J.E., Corell, R., Forsius, M., Kattsov, V., Olsen, M.S., Pawlak, J., Reiersen, L.-O., and Wang, M. 2019. The urgency of Arctic change. Polar Science, 21, pp. 6-13.

Previdi, M., Smith, K.L., and Polvani, L.M. 2021. Arctic amplification of climate change: a review of underlying mechanisms. Environmental Research Letters, 16(9), p. 093003.

Sandy, S.J. 2022. Acoustic Detection and Characterization of Sea Ice and Surface Waves in the Northeast Chukchi Sea. University of Alaska Fairbanks, MS thesis.

Wassmann, P., Carmack, E.C., Bluhm, B.A., Duarte, C.M., Berge, J., Brown, K., Grebmeier, J.M., Holding, J., Kosobokova, K., Kwok, R., Matrai, P., et al. 2020. Towards a unifying pan-arctic perspective: A conceptual modelling toolkit. Progress in Oceanography, 189, p. 102455.

8.0 Appendices

Appendix A: Arctic Synthesis Workshop Agenda

Meeting Agenda
Arctic Marine Biodiversity and Ecosystem Structure Data Analysis & Synthesis

Funded by: Coastal Marine Institute
Location: Endeavor Room, Hotel Captain Cook, Anchorage AK.

Zoom Meeting Link for Plenary Sessions:
https://alaska.zoom.us/j/81114091122?pwd=bzhxOG1EcWtjVmRSTk43RVNXbWxOZz09
Meeting ID: 811 1409 1122
Zoom Passcode: N5lth7iH

26 October 2021

	Plenary Session with Zoom Link: 8:30 to 12:00 and 1:00 to 1:30
8:30 am	Welcome, introductions, comments from funders, meeting plan/objectives overview
9:00 am	CEO program and data holdings overview (Seth)
9:15 am	AMBON program and data holdings overview (Katrin)
9:30 am	DBO program and data holdings overview (Jackie)
9:45 am	Other potential data sets of note for this synthesis (Everyone)
10:00 am	Morning break
10:15 am	Participants present synthesis idea slides (~5 min each)
12:00 pm	Asian Lunch (provided)
1:00 pm	Plenary session: Identify synthesis group breakouts
1:30 pm	Breakout group (Individual zoom session set up on the fly with remote participants as needed.)
3:00 pm	Afternoon break
3:15	Continued breakout group discussions
	Dinner on your own/small groups

27 October 2021

	Plenary Session with Zoom Link: 9:00 to 12:00
9:00 am	Recap of day 1, rapporteurs of break-out groups
10:00 am	Morning break
10:15 am	Plenary discussion with focus on manuscript outlines
12:00 pm	Lunch (on your own)
1:30	Continued breakout group discussions

3:00 pm	Afternoon break
3:15	Continued breakout group discussions
	Dinner on your own/small groups

28 October 2021

Plenary Session with Zoom Link: 9:00 to 12:00 and 1:00 to 2:00

9:00 am	Recap of day 2, rapporteurs of break-out groups
10:00 am	Morning break
10:15 am	Discussion: Conceptual model updates/gaps
11:15 am	Discussion: Research/information needs and agency recommendations
12:00 pm	Fajita Lunch (provided)
1:00 pm	Discussion: Informational flier discussions
2:00 pm	Unfinished business
3:00 pm	Afternoon break
3:15 pm	Meeting wrap-up and action items
	End of meeting

Catering: All-day beverage service (coffee, tea, soft drinks, mineral water) with snacks in the morning (fruit and granola bars) and afternoon (nuts and cookies). Lunch provided on Tuesday and Thursday.

Appendix B: Slides Presented by Workshop Attendees

State of the Pacific Arctic Ocean region from surface to sediments

- Provide an overview of the recent state of the region = present the most important results and general trends from all measured parameters available over a specific period

- Suggested period = 2015-2020 (earlier? shorter? status of analyses?)

- List which additional measurements/information are needed

Are bottom-up or top-down processes more important in shaping and changing Arctic benthic communities?

- Loss of sea ice & earlier ice retreat are generally believed to result in more of the primary production being consumed and remaining in the water column. Presumably, this will benefit pelagic-feeding fish, seabirds and mammals at the expense of benthic predators (i.e. weaker pelagic-benthic coupling)

- Loss of sea ice & earlier ice retreat also leads to 'borealization' ('Pacification'?), including the northward expansion of large predatory fishes, which can have a strong top-down effect on the diversity and abundance of benthic prey (e.g. Barents Sea)
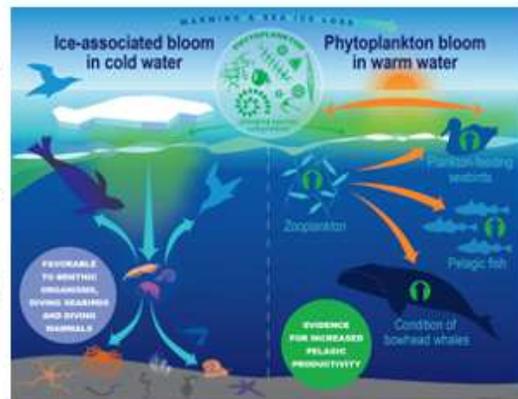
- Questions:
  - Does the available evidence support increased pelagic and decreased benthic productivity in the Chukchi Sea?
  - Has the abundance of predators in the Chukchi Sea changed? If so, what is the impact on the benthic food web? (How are increasing predator abundances in the NBS impacting the benthic food web there?)
  - Approach: (1) Synthesize / update overall time trends for metrics of pelagic & benthic productivity (abundance?) from available time series. (2) Test effects of environmental constraints vs predator constraints on distribution of prey for selected predator / prey pairs (3) Compare NBS benthos pre-/post-expansion of

Changes in remote and local nutrient supply and consequences for lower trophic level production in the Pacific Arctic

- Increased volume transport through Bering Strait has been hypothesized to correspond to additional nutrient supply, but volume transport comprised of several water masses with unique nutrient signatures

- moored observations suggest the winter water nutrients in the northern Bering have actually decreased from 2005-2017 (Mordy et al., 2020) and these changes are well-correlated with bottom water nutrients observed pre-bloom in the Chukchi

- Processes that are responsible for winter water formation are tied to cryosphere/ocean/atm interactions (including heat loss, ventilation) which we know are interannually variable (but what do we know or can we predict about trends??)

- Recent evidence from turbulence and geochemical productivity tracers also suggest that local nutrient supply from wind-forcing must fuel late season productivity when surface waters are otherwise nutrient-limited

- To what extent can we document the importance of seasonal replenishment/advection vs local nutrient supply in supporting the ~30% increase in primary production that is estimated from satellites?

Moore

Has increased 1° production & transport through Bering Strait fostered changes in marine bird and mammal prey availability in the Chukchi Sea?
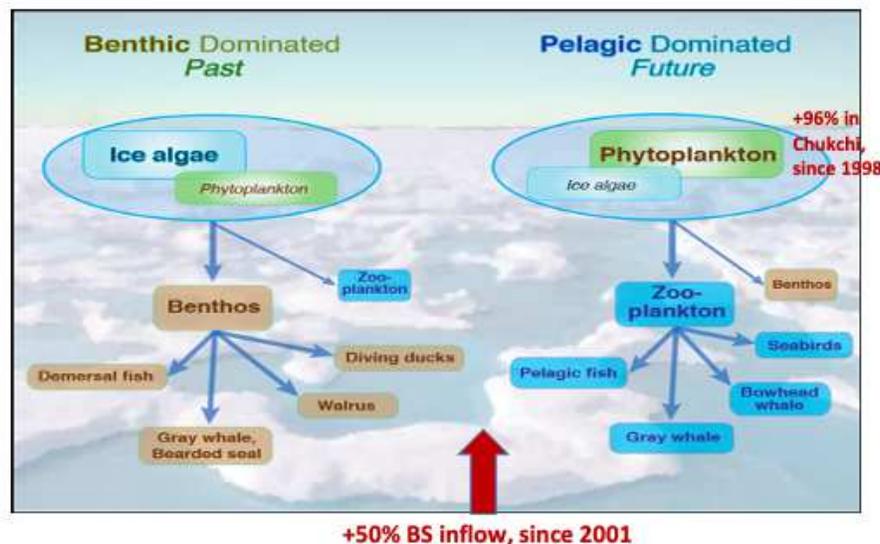
Topics
Assessing ecosystem and biodiversity changes

- Assessing changes in marine bird and mammal species composition, phenology, distribution and prey 'hotspots' in the Chukchi Sea
- Revising aspects of the pelagic-benthic model for the Chukchi shelf
- Importance of krill as focal prey for baleen whales and seabirds
- Increasing top-down predation of baleen whales by orca

Policy and management implications:

- Management of ship strike risk to baleen whales in Bering Strait region
- Management of bycatch of marine birds and mammals from expanded commercial fishing & crabbing operations
- Implications of increasing anthropogenic noise to subsistence species

Galaska

PMEL

Biodiversity responses to a changing Arctic Ocean: Using eDNA and physical ocean measurements to quantify impacts of climate change.

- Utilize cruise eDNA samples (geographic distribution) paired with moored automated samples (temporal) to assess species distribution and seasonality.
- Pair measurements of temp, O2, pH etc, with eDNA metabarcoding (multivariate analyses).
- Build an archive of eDNA samples from the Arctic (used for future studies)
- Identify and fill species gaps in the publicly available nuclear databases (NCBI)
- Expand the set of eDNA primers for species in the US Arctic (Bering and Chukchi Seas)
- Identify species of interest for relative abundance measurements (targeted markers) for future studies

Hennon
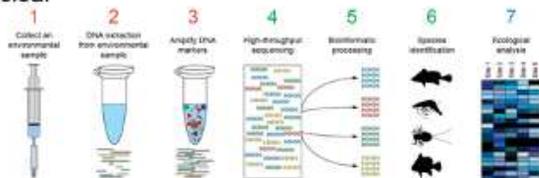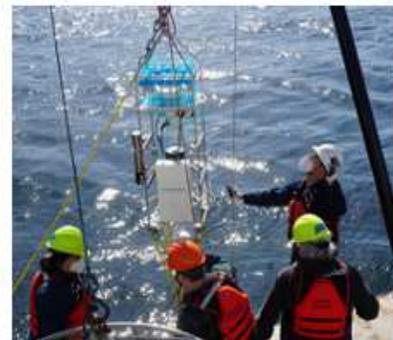
Downstream implications of Arctic-bound nutrient supply through Bering Strait

- We have monthly estimates of Arctic-bound nutrient flux (NO3, PO4, SiO4) through Bering Strait from 1997-2018.

- Can anomalous months or years be correlated with higher/lower values of biological parameters downstream in the Chukchi? E.g. comparisons with chlorophyll, sediment traps, etc.

Annual and seasonal nutrient fluxes through Bering Strait.

Iken
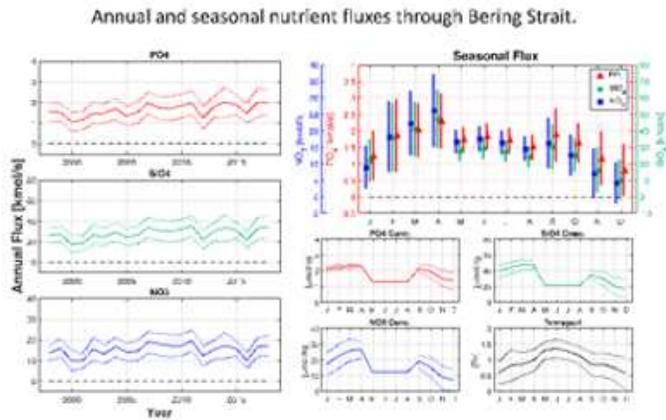
Do biological controls differ across the northeastern Chukchi? Top down vs bottom up?

Walrus feed more on the eastern side of Hannah Shoal than the western side

- Does this lead to top-down control (cropping)?
- Is it more bottom-up controlled with fewer walrus?
- Does this lead to a different distribution between macrofauna and epifauna?
    - Differences in biomass?
    - Differences in food web structure?
    - Differences in productivity (P/B)?

Young et al. 2017
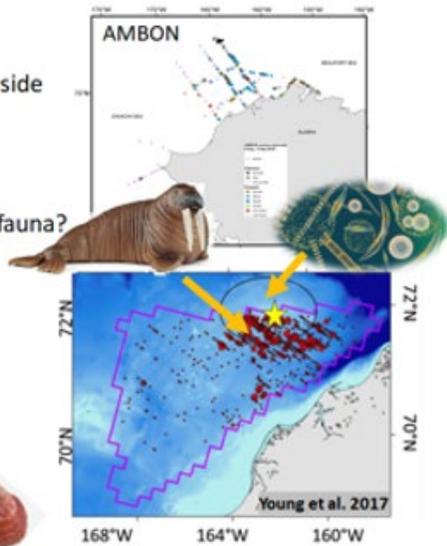
Changes in functional trait space: an ecosystem perspective

- Multi-trophic level (plankton to whales) changes in functional diversity over time and space

- Compare trait space to sea ice extent and temperature

Sutton

AMBON 2015   AMBON 2017

Functional trait space

Time

Sousa
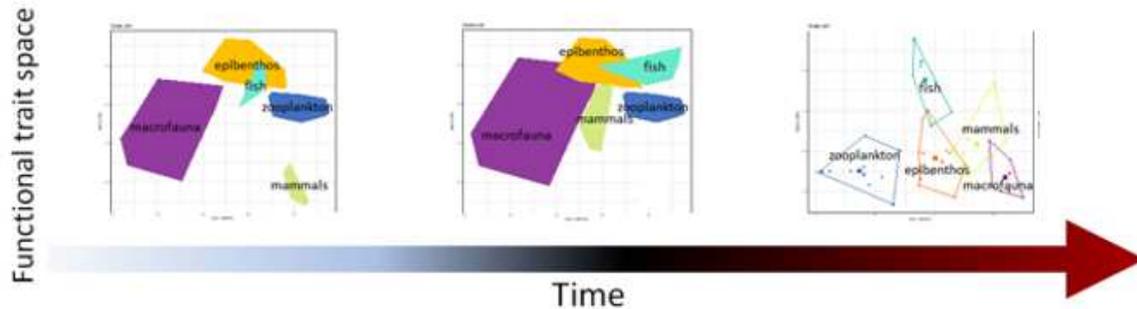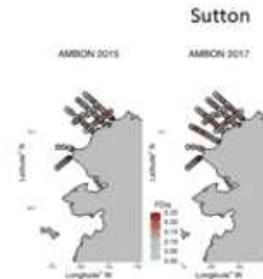
Title: Seasonal differences in under ice aggregations of zooplankton and fish and their association with water masses

1. Fish and plankton aggregations are denser in spring/break-up and late fall/freeze-up.

2. Zooplankton vertical distribution will vary with pycnocline depth and DVM, however nearshore vertical distributions show stronger associations to tidal height.

3. Break-up in the nearshore is influenced by coastal runoff while in the offshore it is not.

4. What is the variation of the onset of freeze-up (break-up) and its association to ice thickness, solar radiation, water temperature, and wind?

Sousa, Leandra (NSB-DWM)

Cooper

Late Season Observations of Productivity in the Northern Bering and Chukchi Seas: Comparisons with Earlier Seasonal Activity

SIR WILFRID LAURIER CHLOROPHYLL BIOMASS RECORD FROM JULY 2000-2019

NEW DATA FROM OCTOBER 2020 AND POTENTIALLY NOVEMBER 2021 SHOW LATE SEASON PRODUCTION

RELATIONSHIP WITH NUTRIENT CONCENTRATIONS

REMOTE SENSING PROJECTIONS OF CHLOROPHYLL BIOMASS AND PHENOLOGY (KAREN FREY)

HAS CHLOROPHYLL BIOMASS CHANGED IN LAST 20 YEARS? REMOTE SENSING VS. IN-SITU MEASUREMENTS

Lee Cooper, lead

CEO/AMBON Chukchi Ecosystem and Biodiversity Workshop 26-28 October 2021, Captain Cook Hotel, Anchorage, Alaska

Theme: Time series trophic interactions in the Pacific Arctic over variable time and space scales
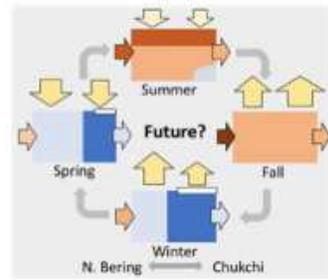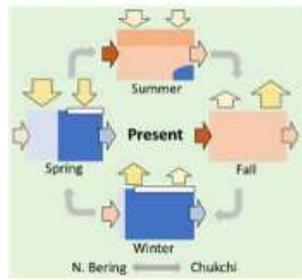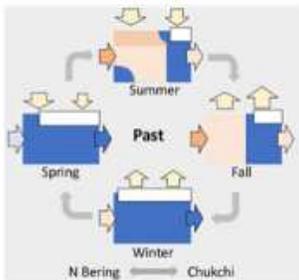
Main underlying ideas for the synthesis paper

> Seasonal changes in latitudinal seawater temperatures are occurring both in surface and bottom waters of the Pacific Arctic in a regional basis, along with reduction of sea ice seasonally. How are these forcing factors influencing benthic populations?

> Indication of macrofaunal change (decrease and increase) regionally in relation to variable phytoplankton production and changing environmental conditions

> Satellite data indicates increased productivity north of Bering Strait with more open water. What impact will this have on pelagic and benthic production?

> Will there be an ecological shift in prey population structure regionally that will impact upper trophic level populations of whales, walrus, and seabirds?

> We are observing changes in bivalve, amphipod and polychaete composition regionally, both in abundance and biomass. What impact will these spatial population changes have on the organic carbon cycling on the shelf system?

> How will ongoing population changes in prey items influence biodiversity in the Pacific Arctic from lower to upper trophic levels?

Grebmeier

Changing ocean habitat over many years driving ecosystem responses in the Chukchi Sea

- Massive environmental change over past decades ... but not fully described.
- How have the biological communities adjusted?
- Can we anticipate future conditions and ecosystem/biodiversity ramifications?

Ocean Temperature
Surface heat fluxes
Ice Cover
Oceanic Advection

[Huntington et al., 2020]

Any change?

5x increase

10x by species

Biomass

Year

Month
○ June
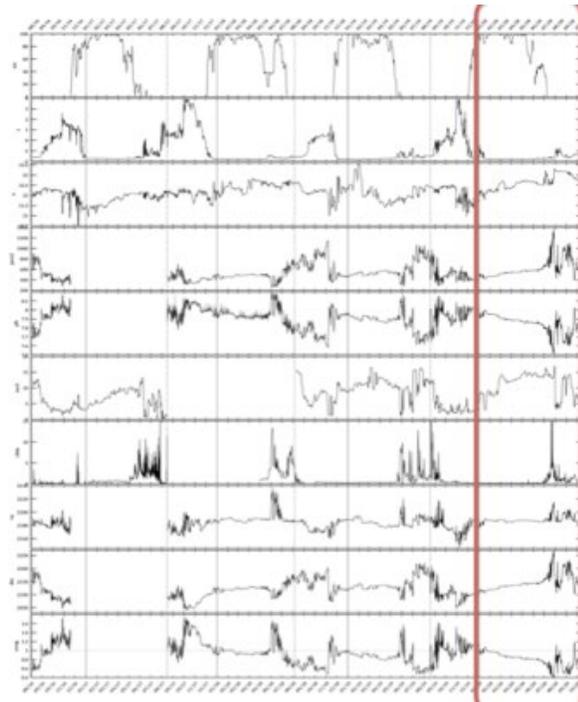○ July
○ August
○ September

Hopcroft

Long-Term Changes in
Summer Zooplankton Communities
of the Western Chukchi Sea, 1945–2012

By Elizaveta A. Ershova, Russell R. Hopcroft, Ksenia N. Kosobokova, Kohei Matsuno, R. John Nelson, Atsushi Yamaguchi, and Lisa B. Eisner

Proposed mechanisms operating in Pacific Arctic heat wave – impacts on Seabirds
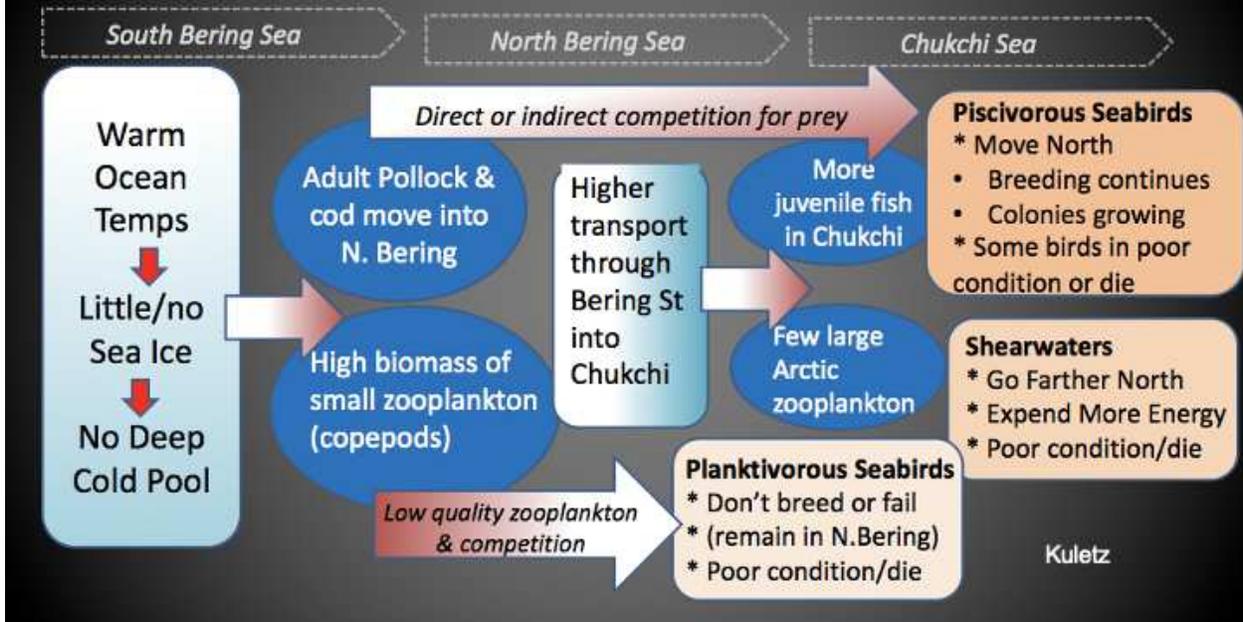
Hauri

- Use CEO to identify "odd" years and compare across programs to understand drivers

- Collaborate on seascapes using CEO and PARROMS-Cobalt
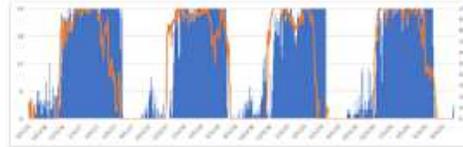
Stafford

Synthesis ideas from CEO mooring

- How do acoustic detection of marine mammals change over time with changing sea ice extent/thickness and water temperature?

- How is the acoustic biodiversity changing over time?
    - Is this linked to changes in prey field?
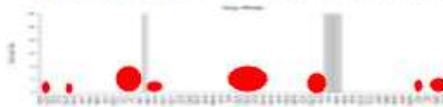   - Is interannual signal greater than long-term signal?
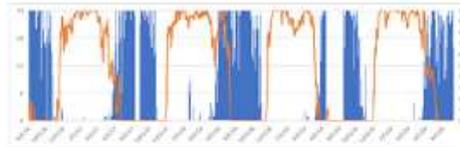
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