

Photo Credit: Brendan Smith/NPRB

# NORTHERN BERING SEA INTEGRATED ECOSYSTEM RESEARCH PROGRAM

## INTEGRATED SCIENCE PLAN

*In the face of rapid changes in the marine ecosystem of the Northern Bering Sea, this program builds collaboration among researchers and regional knowledge-holders to identify important processes that structure the marine ecosystem and food webs, thereby enabling responsible stewardship of important commercial, ecological, and subsistence marine resources.*

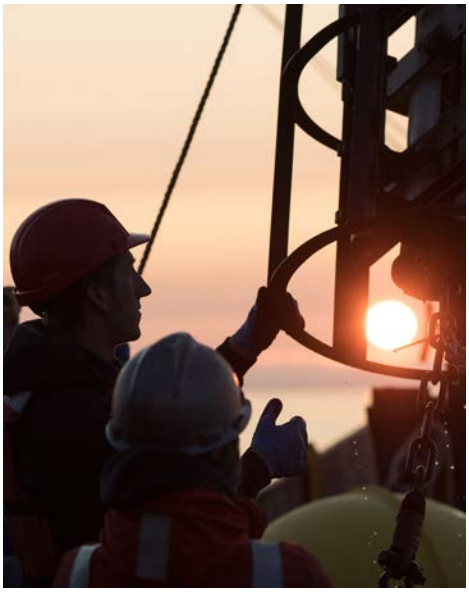
## RATIONALE

Rapid warming is altering ecosystem structure, function, and energy pathways in the Northern Bering Sea (NBS) with major effects on marine resources and communities in this region. During the past decade, the NBS has experienced prolonged periods of record low ice extent and record high temperatures with concurrent ecological effects that included large-scale die-offs of marine species, harmful algal blooms, subsistence harvest moratoriums, and commercial fisheries closures that have severely compromised food security and livelihoods of local community members and the nation. These changes represent an accelerated transition of the NBS from an ice-associated and benthic-dominated ecosystem to a pelagic ecosystem with considerably less seasonal ice.

During 2026-2031, we will use moored instruments, autonomous vehicles, and satellite-based sensors, along with vessel, community, and laboratory based studies to develop a mechanistic understanding of how large- and small-scale physical processes and ice dynamics alter ocean chemistry, benthic-pelagic energy pathways, and food web dynamics from phytoplankton and zooplankton to crabs, fishes, seabirds, and marine mammals.

## WHO IS INVOLVED

This collaborative research program involves scientists from a wide variety of institutions, including leadership by University of Alaska Fairbanks and NOAA Alaska Fisheries Science Center, and co-investigators and collaborators at Nome Eskimo Community, the Native Village of Savoonga, NOAA Pacific Marine Environmental Laboratory, U.S. Fish & Wildlife Service, University of Alaska Anchorage, University of Washington, Bigelow Laboratory for Ocean Sciences, Oregon State University, American University, ABR, Inc., and Alaska Department of Fish & Game. North Pacific Research Board takes an active role in facilitation. The program is intended to serve as a nexus for broader regional collaboration during the 2026-2031 timeframe. Biographies and contact information for the participants are available on the NBS IERP website.



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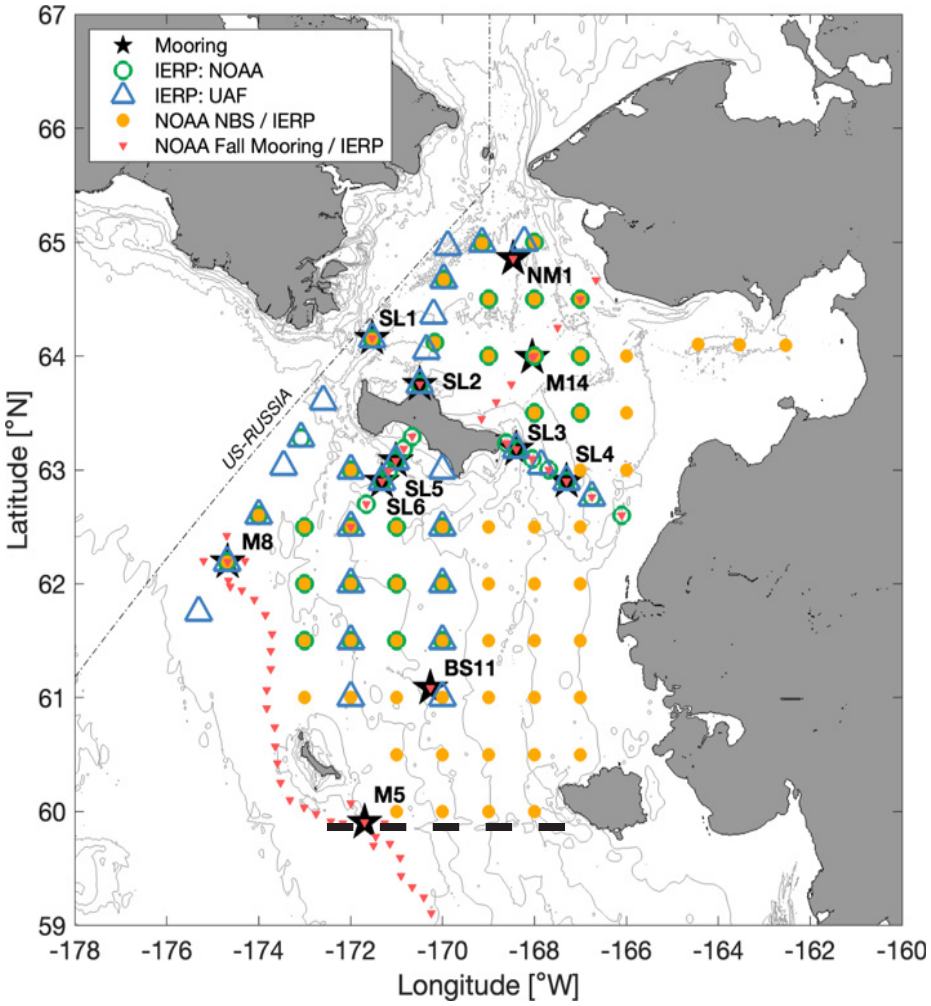


**FIGURE 1. MAP OF THE STUDY LOCATIONS.** Black stars show sites where UAF and NOAA moorings will be deployed from Sept. 2026-Sept. 2029; see Figure 2 for moorings specifically deployed during this field program (M8, M14, SL 1-6). Yellow dots show the upper trophic-level survey sites where NOAA will sample from the F/V *Northwest Explorer* in September annually. Red inverted triangles show sites NOAA will sample from a NOAA vessel in August-September annually. Blue triangles show sites UAF will sample from the R/V *Sikuliaq* in summer 2026 and 2028. Green circles show sites where NOAA will sample from a NOAA vessel in June 2027 and 2029. The dashed line at 60N shows the primary transect line for the SeaTrac in 2027 and 2029.

## OBJECTIVES

1. Characterize seasonal and annual changes in the physical and chemical environment of the Northern Bering Sea.
2. Understand how physical conditions including sea ice, temperature, and mixing of the water column affect plankton growth, nutritional content, species composition, and the timing and size of blooms that support marine food webs in the water column and on the seafloor.
3. Determine how changing food webs and environmental conditions affect populations of ecologically and culturally important marine resources for commercial and subsistence purposes.
4. Foster partnerships among regionally-based project members and collaborators based elsewhere in Alaska and beyond to improve our understanding of physical and biological factors affecting subsistence marine resources and food security concerns.
5. Collect data to improve physical and ecosystem-wide models to inform fisheries management and predict future changes within the NBS.



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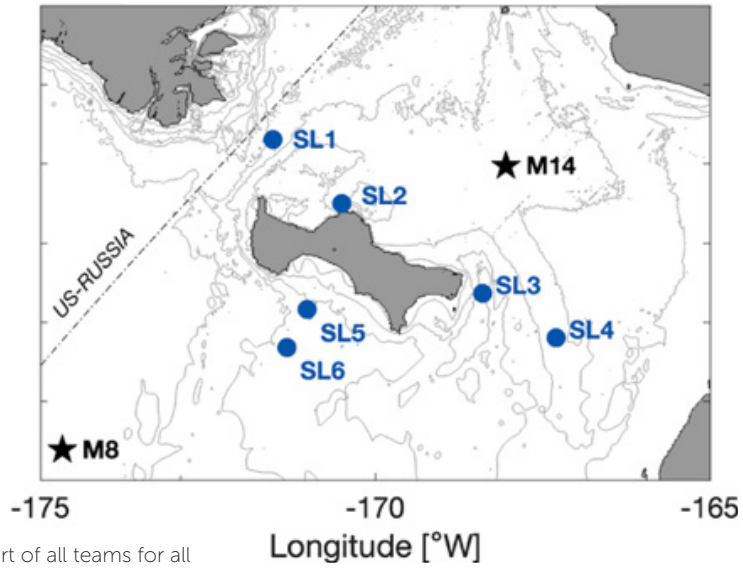


FIGURE 2. MOORING LOCATIONS. These sites reflect the combined effort of all teams for all four field years. M8 and M14 are long-term biophysical moorings maintained by NOAA Pacific Marine Environmental Laboratory. Specific sensors deployed at each site are listed in Table 1.

## RESEARCH METHODS

We will address research objectives using a combination of moored instruments, shipboard measurements, autonomous vehicles, laboratory experiments, and community-based sampling around St. Lawrence Island. Moored oceanographic instruments will be deployed at several sites in the NBS to measure the physics and chemistry of the ocean from September 2026 through September 2029. Biological measurements will be collected from moorings at some sites – these include acoustics to track fish movements and whale calls, and eDNA to track changes in species over time.

Research vessels will survey the region at sites distributed across the study area (*Figure 1*). In September 2026 and 2028, a team of researchers from UAF aboard the R/V *Sikuliaq* will address questions of how distinct temperature and salinity layers in the water column, which result from sea-ice melt, freshwater inputs, and ocean heating, affect plankton production and growth, species composition, and the timing and size of blooms that support the marine food web. In September of each year from 2026-2030, a team of scientists from NOAA will focus on fishes, crabs, marine mammals and seabirds, conducting observations and trawls from the F/V *Northwest Explorer* to assess population sizes and distributions, diets and physiological conditions. In June 2027 and 2029, NOAA and academic scientists will study the oceanography and plankton from the R/V *Oscar Dyson* to assess how changes in the timing of spring sea ice retreat affects the species composition and nutritional quality of plankton and zooplankton.

### Research Objective #1. Characterize seasonal and annual changes in the physical and chemical environment of the Northern Bering Sea.

This objective will be addressed using a combination of moored instruments, shipboard surveys, and surveys using a SeaTrac uncrewed surface vehicle (USV). Six moorings will be deployed in the region in 2026 (*Figure 2*). These moorings will remain in place through 2029, with annual recovery and redeployment to allow servicing and data recovery. The data will not be available in real time, but instead will be available when the instruments are serviced each year. Moorings will record data on current velocities, temperature, salinity, fluorescence (a measure of phytoplankton biomass), nutrients, oxygen, pH, passive acoustics (listening for marine mammals), eDNA, ice profiles, and sinking particles (food for seafloor organisms). This year-round data will enable us to understand the seasonal cycle of physical, chemical, and biological properties in the region over three successive years. Linkages between different variables will also be assessed, for example, variations in phytoplankton biomass or marine mammal movements in relation to temperature. Some mooring sites align with locations where similar

moorings were deployed in previous decades, which will allow us to detect long-term changes in physical and chemical properties including changes to the seasonal cycle.

Shipboard surveys (*Figure 1*) will provide broader spatial coverage of many of the same physical and chemical properties of this region. Instrumentation will be deployed from research vessels to measure vertical profiles of key physical variables through the water column. Water samples will be collected for laboratory analysis to calibrate instrumentation and sample key properties such as nutrient concentrations and pH with higher spatial resolution. The UAF team will also deploy the state-of-the-art In Situ Ichthyo-plankton Imaging System - Deep-focus Plankton Imager (ISIIS-DPI) along transects perpendicular to St. Lawrence Island. This vehicle is "flown" by a shipboard pilot in an undulating fashion along survey transects collecting high-resolution data on physical variables such as temperature and salinity, while also photographing particles and planktonic organisms.

The SeaTrac USV will sample upstream conditions along 60°N including a suite of atmospheric measurements (wind speed and direction, air temperature, relative humidity, and barometric pressure) and oceanographic measurements, both underway (temperature, salinity, chlorophyll fluorescence, currents) and profiles (pressure, temperature, salinity, oxygen, chlorophyll fluorescence). Repeat occupations along 60°N will elucidate tidal and seasonal dynamics of flow, and the front between the inner and middle shelves.

## Research Objective #2. Understand how physical conditions affect plankton growth, nutritional content, species composition, and the timing and size of blooms that support marine food webs in the water column and on the seafloor.

To address objective 2, we will examine the relationships between physical and chemical variables and the growth, community structure, and nutritional composition of planktonic communities, as well as organic particles suspended in the water column and deposited on the seafloor. Moorings and satellite data will be used to measure the timing and magnitude of open water plankton blooms at several locations and water column depths in relation to the annual timing of ice melt. Water samplers on moorings and ships will collect water to determine nutrient concentrations and phytoplankton species composition and biomass, while shipboard experiments will determine plankton growth rates. Ice cores will be collected to determine the species and nutritional composition of ice algae in early spring. Zooplankton communities will be sampled using plankton net tows to characterize community composition and life stages, abundance, and biomass. During the UAF field campaigns (2026 & 2028) the ISIIS-DPI will also be deployed along transects to identify organisms not easily sampled with nets (e.g., gelatinous plankton), and resolve density interfaces and aggregations of particles and

| MOORING SITE | YR1: 2026-27 | YR2: 2027-28 | YR3: 2028-29 |
|---|---|---|---|
| SL1 | T, S, F, N, ADCP<br>Soundtrap | T, S, F, N, ADCP | T, S, F, O2, N, ADCP |
| SL2 | T, S, F, N, ADCP, ST<br>Soundtrap | T, S, F, N, ADCP, ST | T, S, F, N, ADCP, ST |
| SL3 | T, S, F, ADCP, pCO2, O2 | T, S, F, ADCP | T, S, F, O2, N, ADCP |
| SL4 | T, S, F, O2, N, ADCP | T, S, F, O2, N, ADCP | T, S, F, O2, N, ADCP |
| SL5 | T, S, F, ADCP, pCO2, O2,<br>Soundtrap, Fpod | T, S, F, ADCP | T, S, F, O2, N, ADCP |
| SL6 | T, S, F, O2, N, ADCP, IP, WS, ST | T, S, F, O2, N, ADCP, IP, WS, ST | T, S, F, O2, N, ADCP, IP, WS, ST |

**TABLE 1.** The list of six mooring sites and the measurements on each site. Temperature - T, Salinity - S, Fluorescence - F, Nitrate - N, Dissolved Oxygen - O2, Acoustic Doppler Current Profiler - ADCP, Partial Pressure of Carbon Dioxide - pCO2, Passive Acoustic Recorder for Low-mid Frequency Sounds - Soundtrap, Passive Acoustic Recorder for High-frequency Echolocation Clicks - Fpod, Sediment Trap - ST, Ice Profiler to Measure Ice Thickness - IP, Water Sampler - WS. Blue indicates UAF and pink indicates NOAA PMEL provides the moorings. Note: UAF has two T/S measurements (bottom and 20 m) on each mooring.

plankton communities associated with physical features. In addition, a MultiNet plankton net system will be deployed, allowing for discrete sampling above and below density interfaces, as detected by the ISIIS-DPI, to determine how physical features influence the spatial distribution of zooplankton species. For example, we hypothesized that declining sea ice in the region will lead to more mixing of the water column, changing availability of nutrients, and in turn altering plankton community structure.

Links between plankton community structure and nutritional quality of food particles available to consumers will be evaluated by measuring the chemical composition of organic particles, including live phytoplankton cells and sinking detritus. Suspended particles will be collected at different depths on UAF cruises using pump samplers, and sinking particles will be collected at roughly monthly time intervals throughout the year using moored sediment traps. The UAF and NOAA teams will also collect seafloor sediments to analyze the nutritional value of particles deposited at the seafloor in different parts of the study area as an estimate of food "quality" for benthic feeding organisms. Sediments will also be used in experiments on board the ship to measure the metabolism of communities of organisms living in sediments to determine how readily they consume the organic material that settles to the seafloor. These measurements will be used to develop an understanding of how large and small scale physical processes and ice-associated dynamics alter the NBS ecosystem.

## Research Objective #3. Determine how changing food webs and environmental conditions affect populations of ecologically, culturally, and commercially important species.

We will address Objective 3 using field and laboratory studies along with biochemical and fish diet analyses to understand the consequences of changes in energy flow through the northern Bering Sea food web. One aspect of the food web that we are studying is how ice-associated (sympagic) primary production versus open water (pelagic) production differentially affects the growth, condition, distribution, and abundance of pelagic and benthic (seafloor-dwelling) organisms. We are using a multi-faceted biotracer approach to understand energy flow through NBS food webs. Stable isotopes, fatty acids, and isoprenoids (IP25) will be used to differentiate the dietary importance of primary production resources and provide time-integrated information about food web relationships.

Changes in the food web and a general warming trend in the NBS also has the potential to affect the annual timing (phenology) of biological processes and life history of individual organisms. We will use otolith microstructure analysis to determine daily age of juvenile fish to back-calculate hatch dates and estimate daily growth rates to understand how ambient conditions and diet affect hatch timing and growth of fish during vulnerable early life stages. However, disentangling the effects of temperature and diet on growth and survival can be challenging from field observations alone. Therefore we are also using controlled laboratory experiments to investigate whether slower-growing fish have higher mortality at higher temperatures than faster-growing individuals and whether faster growth rates result in a change in body condition. Food web components will be collected during spring and fall cruises. Spring cruise sample collection will include ice algae, phytoplankton, zooplankton, seafloor sediments, and seafloor-associated organisms such as juvenile flatfish and crabs. Fall cruise sample collection will include these same items (except ice algae) in addition to juvenile pollock, cod, salmon, and forage fishes such as herring and capelin.

We will investigate changes in species distribution and predator-prey relationships of juvenile crabs and juvenile fishes and their predators using small-mesh beam trawls, surface trawls (juvenile crabs, fishes, and immature salmon), and large-mesh bottom trawls (subadult and adult crabs and fishes) at fixed survey stations covering the NBS, as well as otolith and eye lens microchemistry and genetics from juvenile and adult fish. Whereas the various trawls permit quantification of changes in horizontal overlap among predators and prey, diet analysis of focal predators permits quantification of direct predator-prey interactions. Chemical analysis of hard parts provides timelines of changes in diet and movement, whereas genetic analyses identify stock origin and distribution that are important for fisheries management. Additional predator-prey interactions that we are investigating include seabirds-zooplankton and fur seals-salmon/pollock. Auklets nesting on St. Lawrence Island have greater reproductive success when feeding their chicks large copepods and krill, and recent studies indicate that fur seals consume more salmon and less pollock with increasing temperatures.



Photo Credit: Matthew Baker/NPRB

We will also investigate timelines of transition in the NBS. We will measure temporal changes in the pelagic fish community on seasonal and interannual scales with two seafloor-mounted echosounder moorings collecting year-round measurements of fish abundance and movement. These echosounders will be co-located with the biophysical moorings, allowing for the direct association of environmental forcing (e.g., currents, temperature, water masses) with seasonal changes in the fish community. We will use environmental DNA to characterize seasonal and annual changes in species composition from mooring-based and vessel-based water sample collections. Seabirds and marine mammals will be surveyed from research vessels during cruises and passive acoustic recorders will provide key year-round data on the timing of occurrence, distribution, habitat use, and migratory routes of vocalizing marine mammals. Furthermore, we will analyze fishing vessel activity to quantify interannual variation in vessel movement and distances traveled with changing commercial fish populations.

**Research Objective #4.** Foster partnerships among regionally-based project members and collaborators based elsewhere in Alaska and beyond to improve our understanding of physical and biological factors affecting subsistence marine resources and food security concerns.

A core goal of this program is to develop collaboration between Indigenous and other regional knowledge-holders and western scientists to achieve program objectives. In the NBS, marine ecosystems are inseparable from the cultural, economic, and physical well-being of the region's residents. This program establishes formal partnerships with three regional Tribal governments, including Principal Investigators (PIs) from the Native Village of Nome and the Native Villages of Nome, Savoonga, and Gambell alongside other working partnerships across the region, such as Alaska Sea Grant. Tribal partners are integral in data collection and interpretation, playing a critical role in nearshore sampling, for example to collect sea ice to study the sources of algae entering the food web. Community-based projects will also investigate subsistence-harvested food resources, including study of the possible causes of declines in the 'sea peach' (uupa) near Savoonga, measuring mercury levels in harvested marine mammals, examining changes in seabird and fish populations, and collecting samples to help understand the dynamics of harmful algal species around the island. Communities will have access to the Indigenous Sentinels Network platform and will continue to develop community-led science initiatives as the program matures.

Local experts hold generations of empirical data regarding sea ice dynamics, weather patterns, and marine wildlife behaviors, disease events and the status of populations. Honoring this knowledge ensures our research is accurate,

collaborative, and directly responsive to the needs of those who rely on these waters for commercial and subsistence purposes. Local observations of shifting ice and ocean conditions have already informed design of the field program, and will ground-truth physical data going forward (*Objectives 1 & 2*), while community insights into the health, behavioral changes, and availability of harvested species have shaped program objectives and will directly inform food web and population assessments (*Objective 3*). Ultimately, these collaborative insights ensure that the predictive ecosystem models we develop (*Objective 5*) are not just theoretically sound, but practically useful for regional fisheries management and community resilience in a rapidly changing Arctic.

A data archive will be established and housed locally in the Native Village of Savoonga as a repository for results of this program as well as other research conducted previously in the region, such that partnering Tribal organizations retain physical access to these data. Findings will be shared more broadly in the study region through iterative, culturally responsive methods being designed in tandem with the Tribes. These will include educational activities for local students, community meetings, regional radio broadcasts, and co-created, translated plain-language reports—guaranteeing that the data generated serves the dual purpose of advancing marine science and supporting community resilience.

## Research Objective #5. Collect data to improve physical and ecosystem-wide models to inform fisheries management and predict future changes within the NBS.

To complement the observations and explore the impact of sea-ice loss on NBS ecosystems, we will use a state-of-the-art numerical model of the ocean that includes sea ice and nutrient cycling to analyze NBS ocean conditions over the past decades. As part of NOAA's Changing Ecosystems and Fisheries Initiative (CEFI), a high resolution ocean general circulation model based on the Modular Ocean Model version 6 (MOM6) has been developed for the Northeast Pacific (MOM6-NEP). MOM6-NEP is used to recreate the past ocean states (from 1993 to the present) and explore how environmental change impacts this ecosystem, as well as to forecast its future. Since the goal of CEFI is to support decision-making in marine resources and fisheries management, calibration of the MOM6-NEP enabled by this project will contribute to management of this complex ecosystem.



Photo Credit: Brendan Smith/NPRB

We also will develop environmentally informed population abundance and distribution models for priority species. For salmon, we will apply a recently developed integrated population model (IPM) for Yukon Chinook salmon to link life stage-specific population dynamics with ecosystem conditions in the NBS. This model leverages juvenile stock-specific indices of salmon abundance from our cruises, data on bycatch of immature salmon, and adult harvest and escapement data to model the full life cycle of salmon stocks. This model framework can be used to explore how changing environmental conditions impact the population dynamics of other imperiled western Alaska salmon stocks.

For groundfish and crab, we will develop a spatially explicit, integrated modeling framework to understand how environmental drivers could be affecting distributions, predator-prey overlap, diet, and juvenile abundance and condition of pollock, Pacific cod, and snow crab. We will use spatiotemporal modeling approaches to combine existing bottom and surface trawl survey data from the NBS. These combined survey datasets will be used to explore patterns of overlap between groundfish and key prey species of juvenile fish crabs.

# *APPENDIX I: LINKS TO FULL RESEARCH PROPOSALS*

Please note that after the three projects that comprise the Northern Bering Sea Integrated Ecosystem Research Program were awarded funding, the scientists worked to integrate their respective research plans. The details that appear in the Integrated Science Plan (e.g., Figures 1 and 2 illustrating the locations of shipboard stations and moorings) supercede the information that appears in the original science proposals linked below.

- Project NBS-68 Oceanography and Lower Trophic Levels, Lead Institution: University of Alaska Fairbanks "StratiFIED-NBS: Stratification and Fronts Influencing Ecosystem Dynamics in the Northern Bering Sea"
- Project NBS-76 Oceanography and Lower Trophic Levels, Lead Institution: NOAA Alaska Fisheries Science Center "Lower Trophic Responses to Warming: Impacts of Sea Ice Loss on Productivity in a Heterogeneous Northern Bering Sea"
- Project NBS-70 Upper Trophic Levels, Lead Institution: NOAA Alaska Fisheries Science Center "Food Web Effects On Species Distribution and Interactions In The Northern Bering Sea"

# *APPENDIX II: DETAILED HYPOTHESES*

## UAF OCEANOGRAPHY & LOWER TROPHIC LEVELS

1. Wind direction and strength control stratification in the Northern Bering Sea, by altering sea ice extent, controlling pathways of water-mass movement, altering the reversing east/west flow south of St. Lawrence Island, and driving anomalous Ekman transport.
2. Weak stratification results in increased mixing at depth, whereas a strong pycnocline limits the delivery of nutrients to the euphotic zone and increases the importance of lateral nutrient fluxes.
3. Strong stratification supports near-bottom phytoplankton production, trapping labile particles near the seafloor.
4. Strong stratification restricts surface phytoplankton to the upper mixed layer, and causes accumulation of surface-derived particles at the pycnocline.
5. Weak stratification favors resuspension events that initiate blooms of viable phytodetritus and encysted microalgae, including diatoms and *Alexandrium catenella*, with outcomes dependent on ambient nutrient and temperature conditions.
6. Contrasting water-mass properties spatially structure bacterio-, phyto-, and zooplankton communities across the NBS.
7. Accumulation of particles along stratified water-mass boundaries provide a concentrated pelagic feeding environment favoring enhanced trophic coupling.

## NOAA OCEANOGRAPHY & LOWER TROPHIC LEVELS

1. Increased advection of warmer water from the southeastern Bering Sea will increase bottom temperatures, thus reducing habitat for cold-adapted organisms and expanding habitat for subarctic species.
2. With earlier ice retreat, export of ice algae to the benthos occurs earlier in spring, is lower in magnitude, and is a smaller fraction of total export; more nutrients remain in the upper water column to support spring blooms of lipid-rich diatoms that feed the pelagic food web.
3. With loss of ice in NBS-S, salinity stratification will weaken, and the timing of the spring bloom will depend on the onset of thermal stratification (e.g., wind relaxation).
4. Ice algae, relative to spring phytoplankton blooms, are composed of larger phytoplankton taxa that are rich in lipids, increasing the quality of primary production available to the food web.

## NOAA OCEANOGRAPHY & LOWER TROPHIC LEVELS (CONT.)

5. Warmer conditions in the shallower NBS-N results in increased summer phytoplankton growth and accumulation near the benthos, due to sufficient light at the seafloor and nutrient replenishment.
6. With earlier ice retreat, the contribution of ice algae to zooplankton diets will decrease relative to the contribution of pelagic phytoplankton resulting in lower lipid content, reproductive rates, and abundance of large-bodied copepods.
7. With earlier ice retreat, fish larvae will be less abundant and in poorer condition

## NOAA UPPER TROPHIC LEVELS

1. Warming temperatures reduce benthic-pelagic coupling with early ice retreat negatively affecting benthic foraging species and positively affecting pelagic foraging species.
2. Warming temperatures affect phenology and life history with earlier hatch-timing and larger size-at-age, but negatively affect body condition of juvenile and subadult pelagic fishes.
3. Cold pool dynamics will affect species distribution, predator-prey interactions, and bottom-up versus top- down control.
4. Warming will accelerate arrival of migratory fish, bird, and mammal species and transition the Northern Bering Sea away from primarily juvenile habitat for many species.