

# RANGE-WIDE GRAY WHALE SCIENCE SYMPOSIUM



**September 9-10, 2026**

Hatfield Marine Science Center

Newport, Oregon



**Oregon State University**  
Marine Mammal  
Institute

## Session 3

### Ecosystem Changes Impacting Gray Whales

*Moderator: Jason Baker, Marine Mammal Commission*





**NOAA**  
**FISHERIES**

SWFSC

# Patterns of change in the Northeast Pacific

Nate Mantua

NOAA Southwest Fisheries Science Center

Fisheries Ecology Division

Santa Cruz, CA

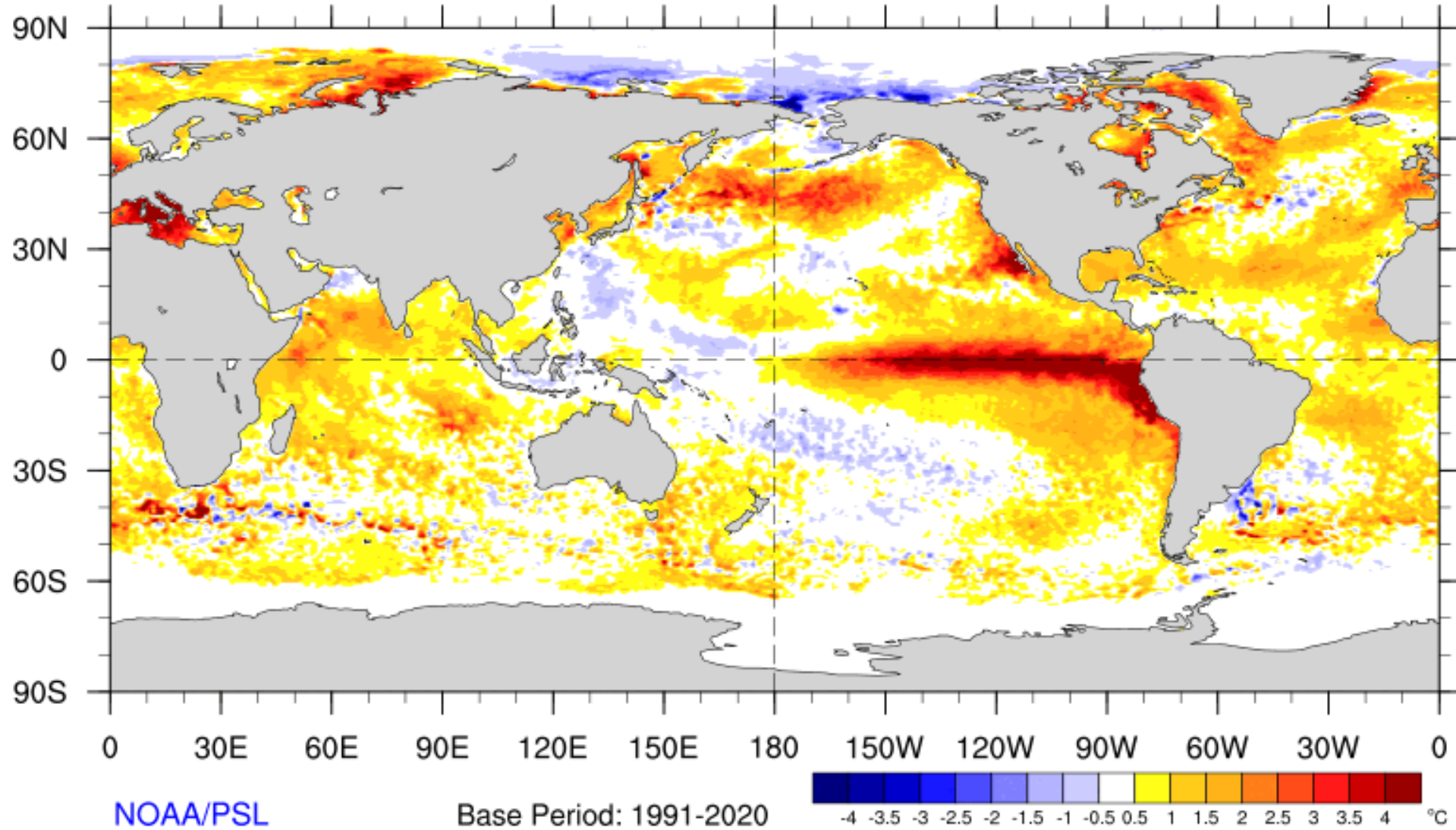
Range-wide Gray Whale Science

Symposium

September 9, 2026

## Daily SST Anomaly

2026/09/07



<https://psl.noaa.gov/map/clim/sst.shtml>

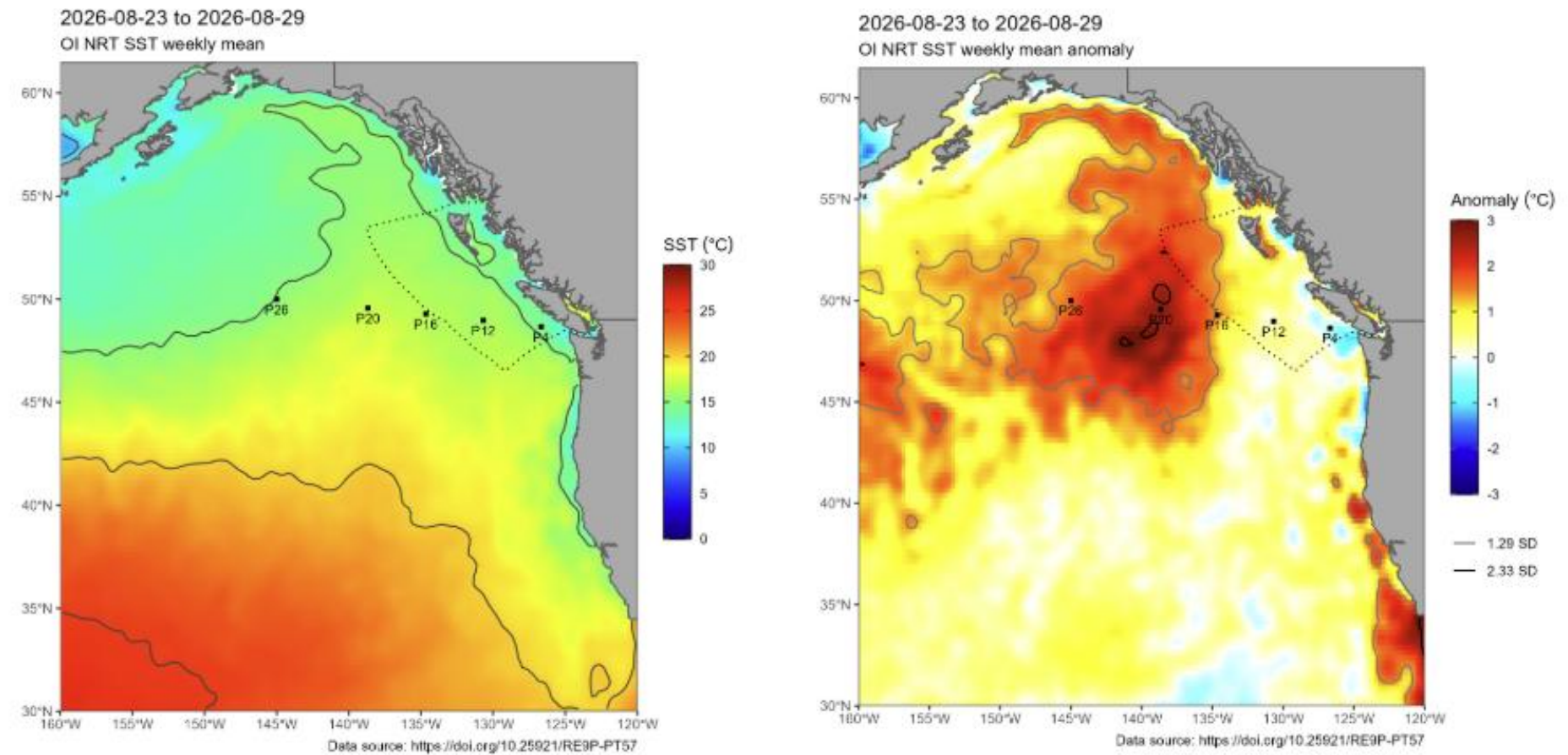


# SST in the NE Pacific from A. Hilborn, C. Hannah, and L. Guan

[https://ios-osd-dpg.github.io/Pacific\\_SST\\_Monitoring\\_Site/](https://ios-osd-dpg.github.io/Pacific_SST_Monitoring_Site/)

Late August 2026

A marine heatwave event underway in the NE Pacific



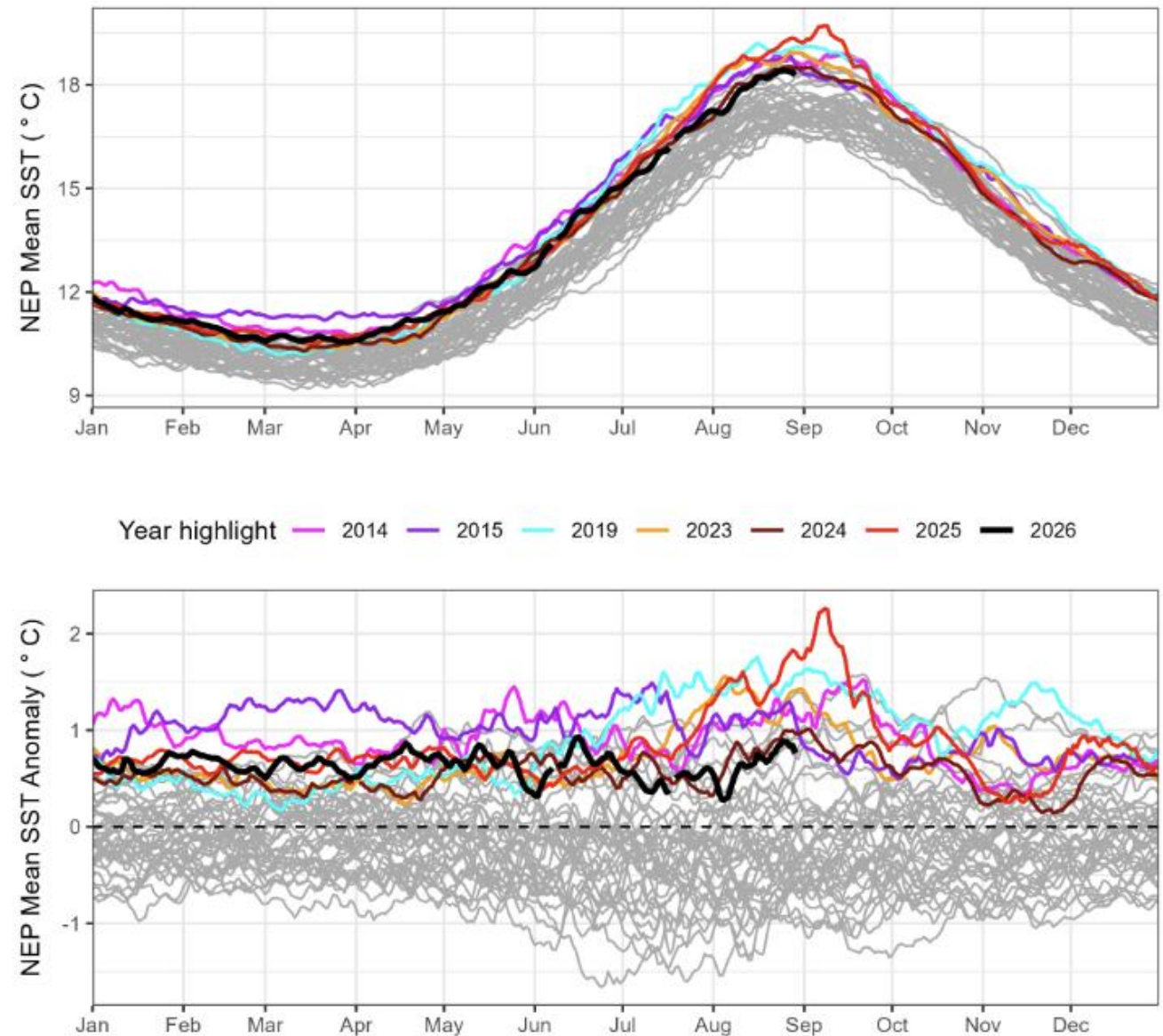
*5-degree intervals are marked as lines on the SST plot (left). On the anomaly plots (right) the lines outline areas of SSTs above 1.29 and 2.33 standard deviations compared to normal (i.e., the upper 90th and 99th percentiles relative to the climatological baseline). The BC EEZ is indicated with a dashed line. Points indicate selected stations along Line-P.*

## SST in the NE Pacific from A. Hilborn, C. Hannah, and L. Guan

[https://ios-osd-dpg.github.io/Pacific\\_SST\\_Monitoring\\_Site/](https://ios-osd-dpg.github.io/Pacific_SST_Monitoring_Site/)

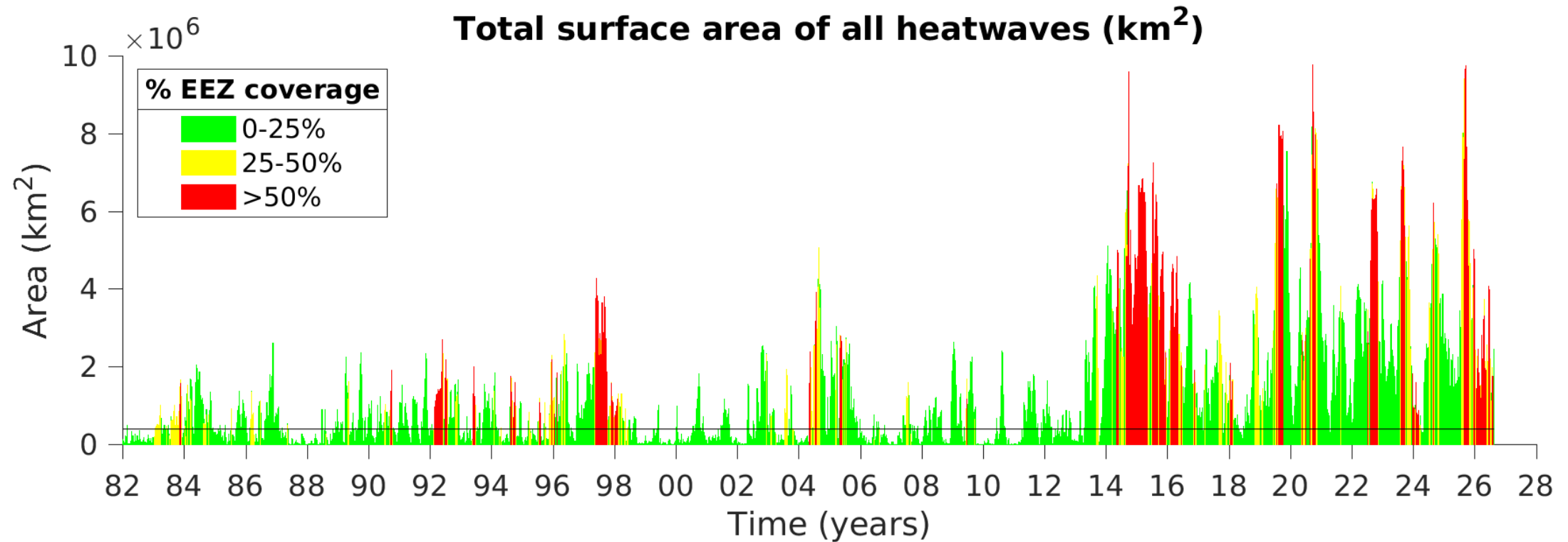
The NE Pacific had 7 years with  
extended marine heatwaves from  
2014-2026

- These have come in all seasons,  
with the largest SST anomalies in  
late summer



Data source: <https://doi.org/10.25921/RE9P-PT57>  
Data last updated: 2026-08-29  
Plot last updated: 2026-08-31

# California Current Marine Heatwaves are increasing



<https://www.integratedecosystemassessment.noaa.gov/regions/california-current/california-current-marine-heatwave-tracker-blobtracker>

# nature climate change

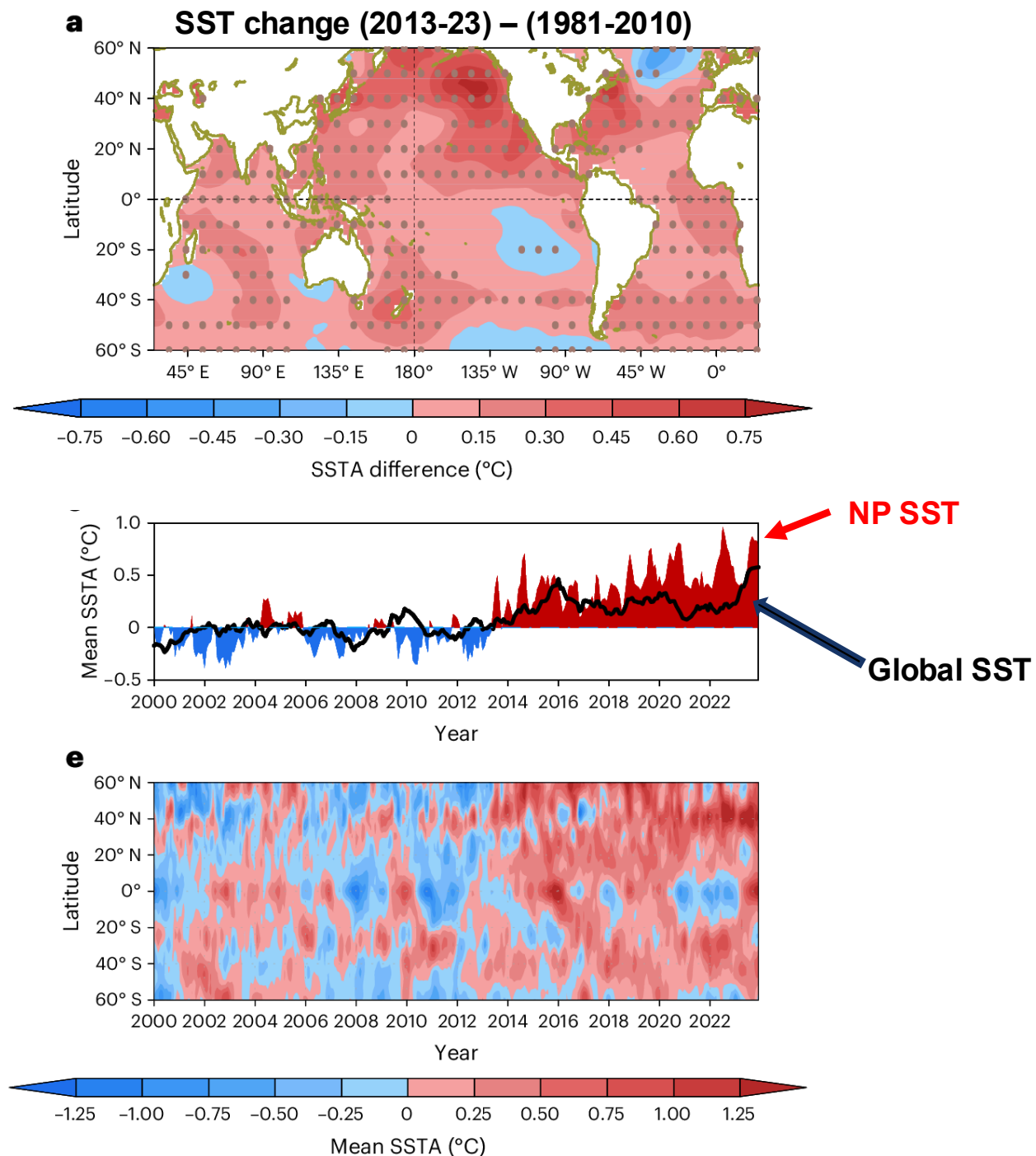
Brief Communication | Published: 23 July 2024

## Accelerated warming in the North Pacific since 2013

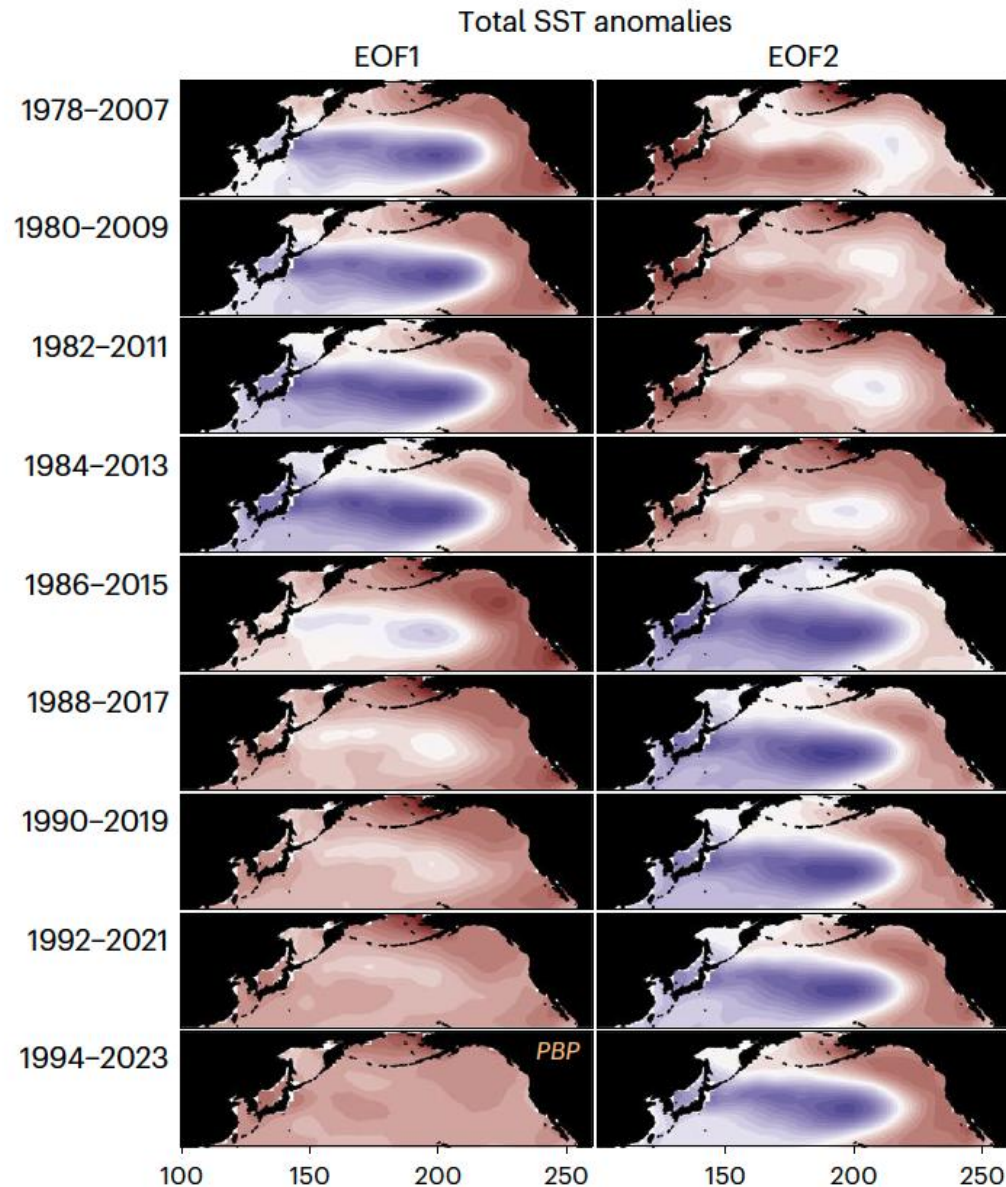
[Zeng-Zhen Hu](#) , [Michael J. McPhaden](#), [Boyin Huang](#), [Jieshun Zhu](#) & [Yunyun Liu](#)

[Nature Climate Change](#) **14**, 929–931 (2024) | [Cite this article](#)

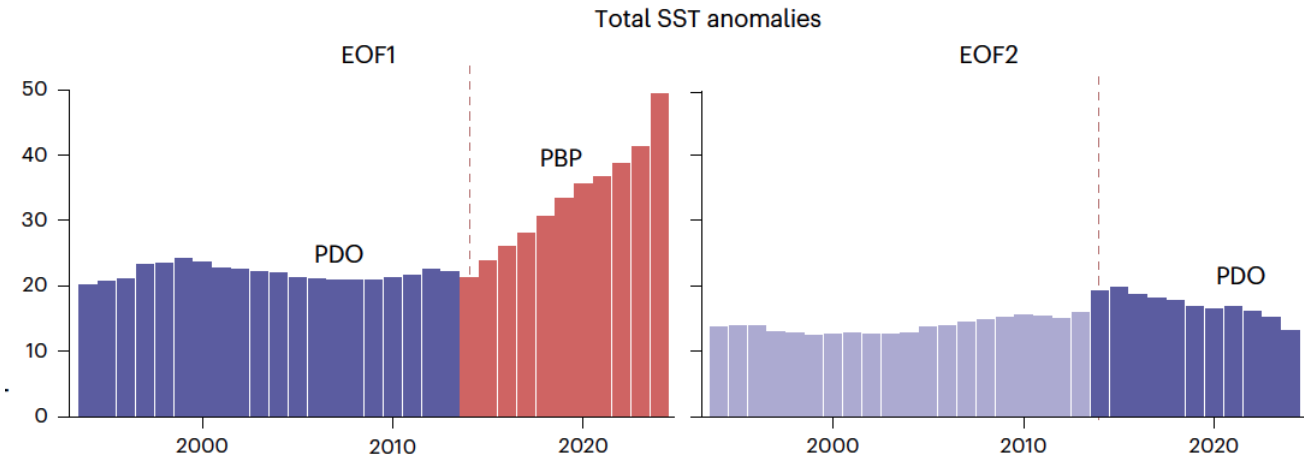
From 2013-2023 warming in the North Pacific was significantly higher than in other basins.



# Pan-basin warming now overshadows a still robust Pacific Decadal Oscillation



Variance explained (%)



- PDO variability appears unchanged and ongoing
- the pan-basin warming pattern became dominant ~2014

Cluett et al 2025:

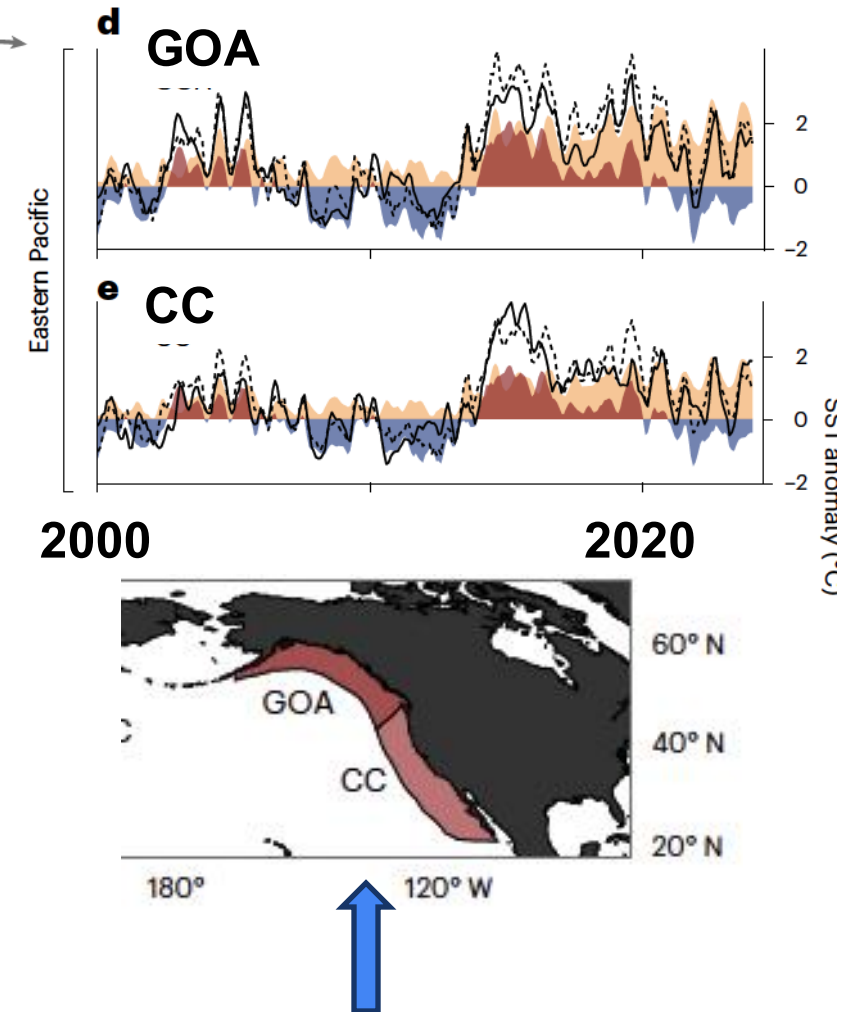
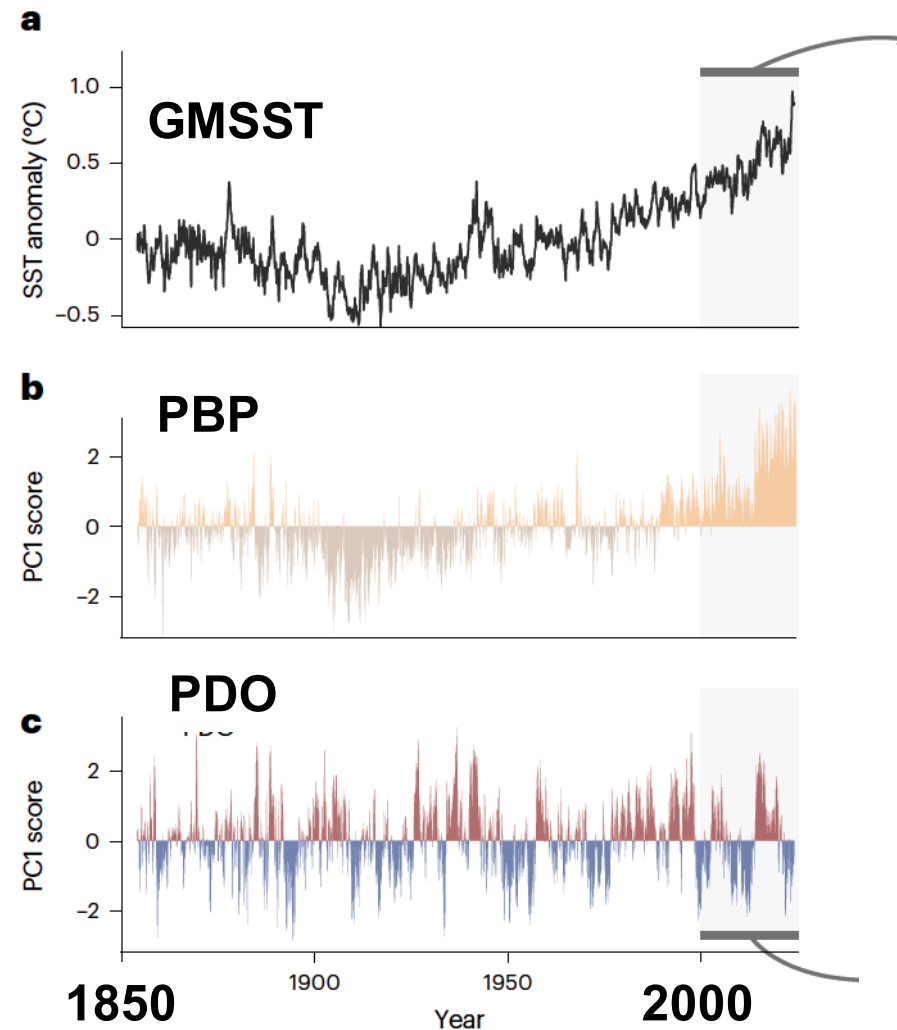
<https://www.nature.com/articles/s41558-025-02482-z>

# Evolving patterns

- PDO contributions to North Pacific SST variations continue, but they are increasingly overshadowed by the pan-basin pattern of warming

Cluett et al 2025:

<https://www.nature.com/articles/s41558-025-02482-z>

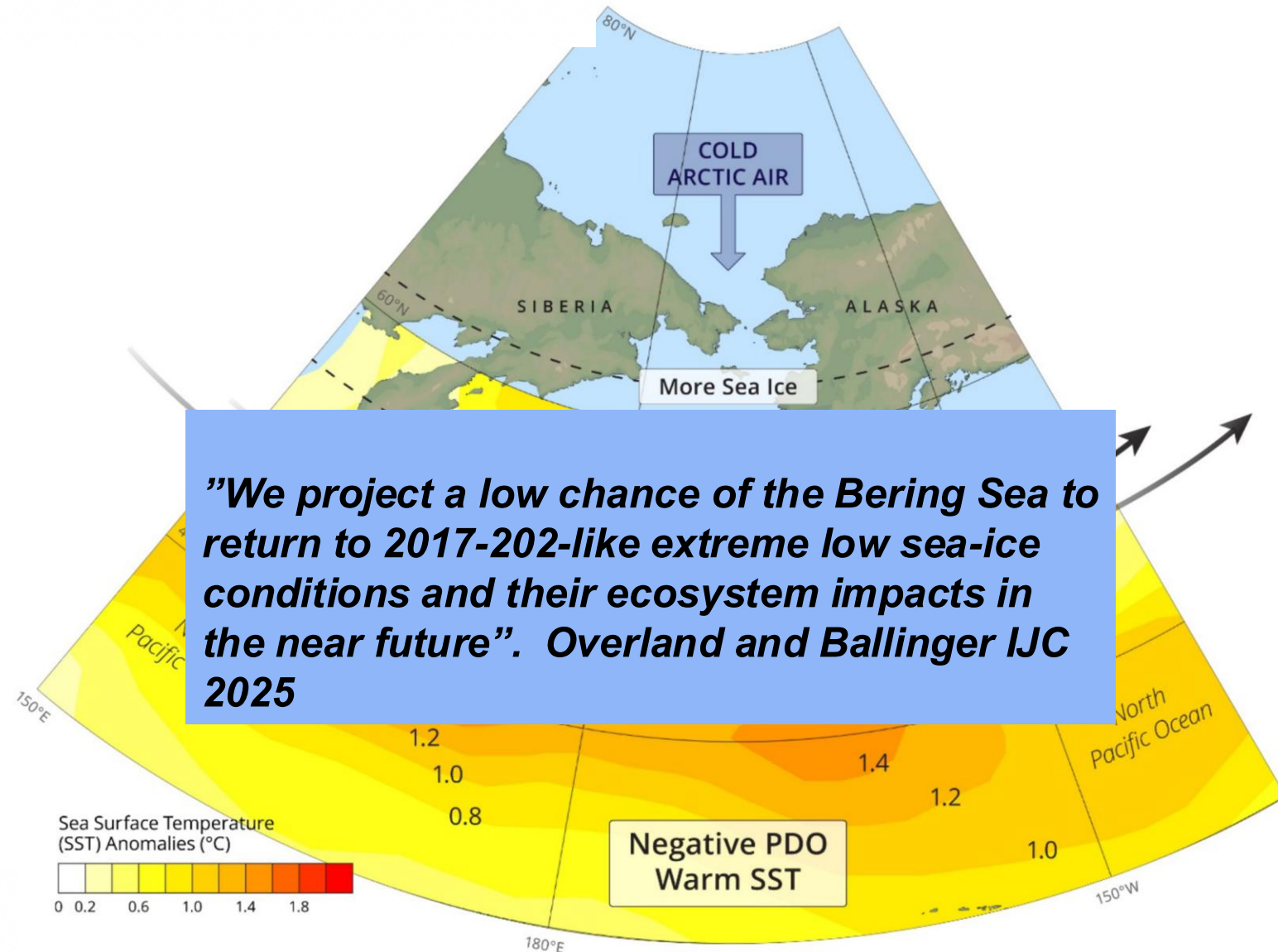


PBP contributions in yellow, PDO in red/blue, combined with dashed line, solid line is observed

# Intradecadal Climate Stanzas for the Northwestern Pacific Ocean and Remote Influence on the Bering Sea

James E. Overland<sup>1</sup>  | Thomas J. Ballinger<sup>2</sup> 

- a short period shift to positive PDO conditions came with 2017-2020 increase in storminess, persistently southerly winds, warm temperatures, and record minimum sea ice in the Bering Sea
- Hypothesize a teleconnection between North Pacific SST and Bering Sea sea ice mediated via the Aleutian Low
  - Ongoing negative PDO conditions part of the return to historical Bering Sea sea ice conditions from 2021-2025

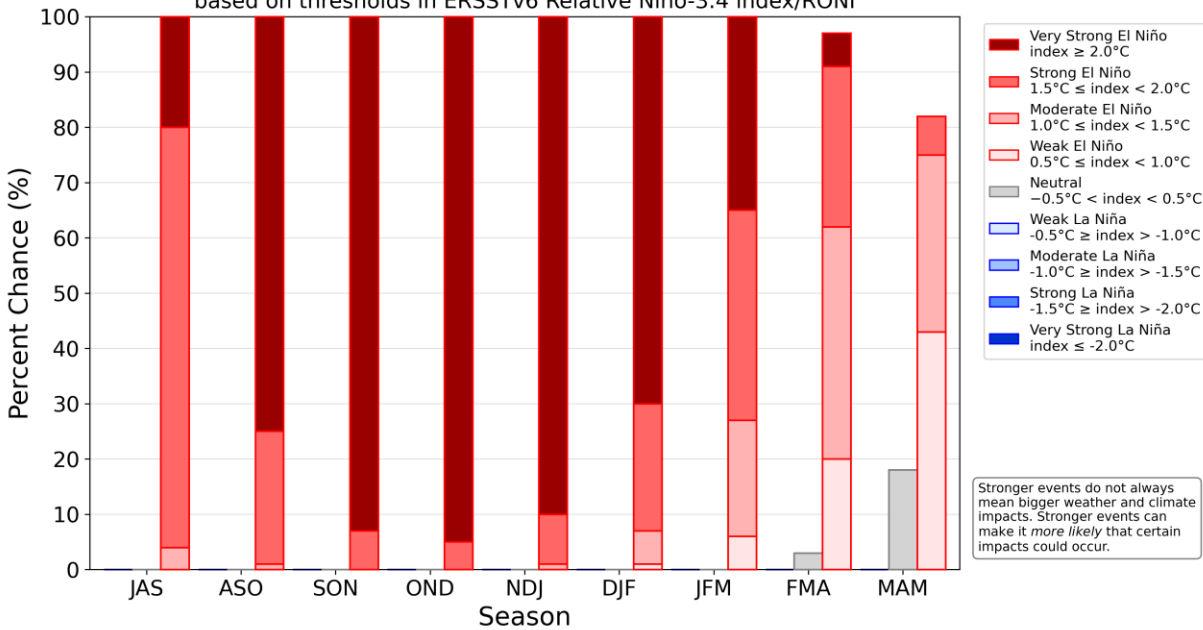


# Outlooks for 2026-27

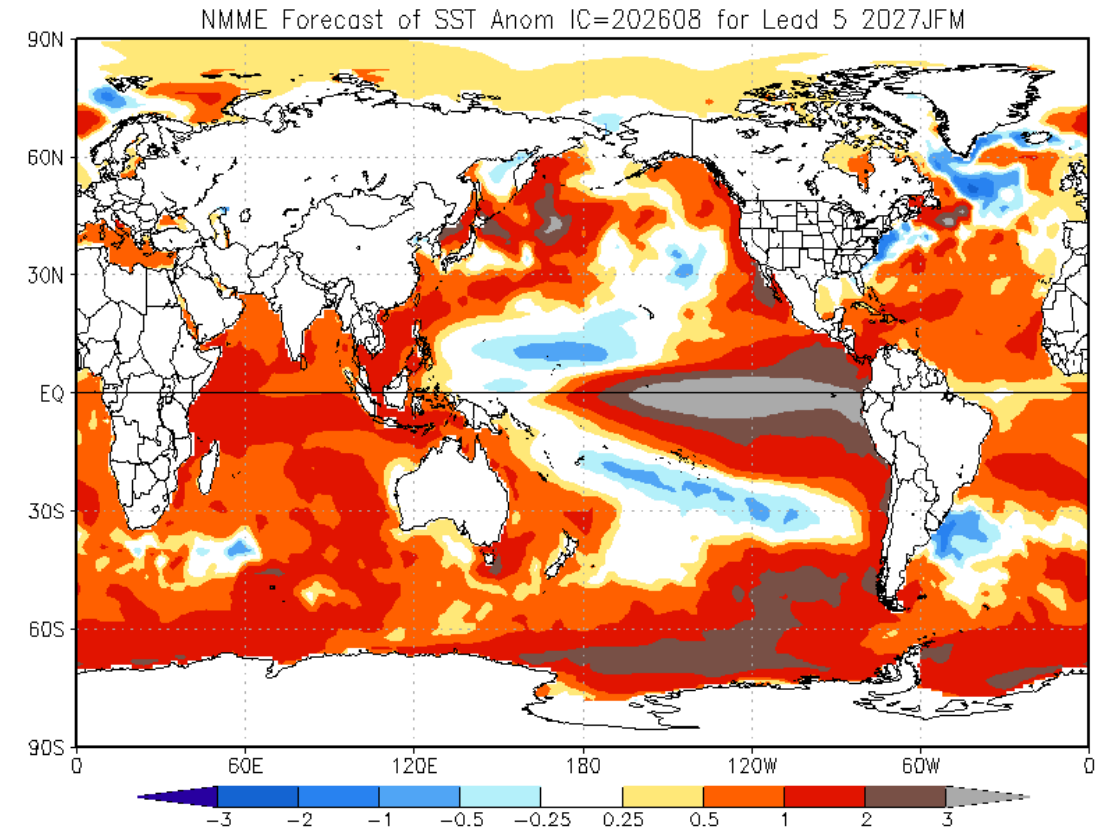
## NMME forecast for JFM 2027 (from August)

### NOAA CPC ENSO Strength Probabilities (issued August 2026)

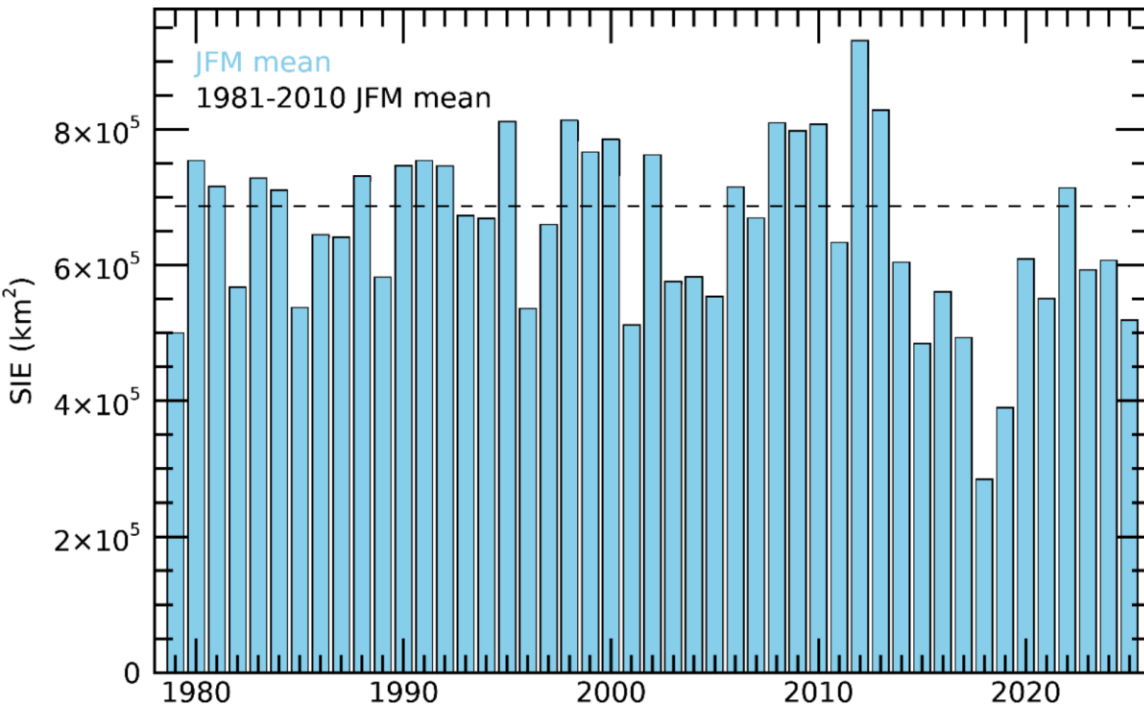
based on thresholds in ERSSTv6 Relative Niño-3.4 index/RONI



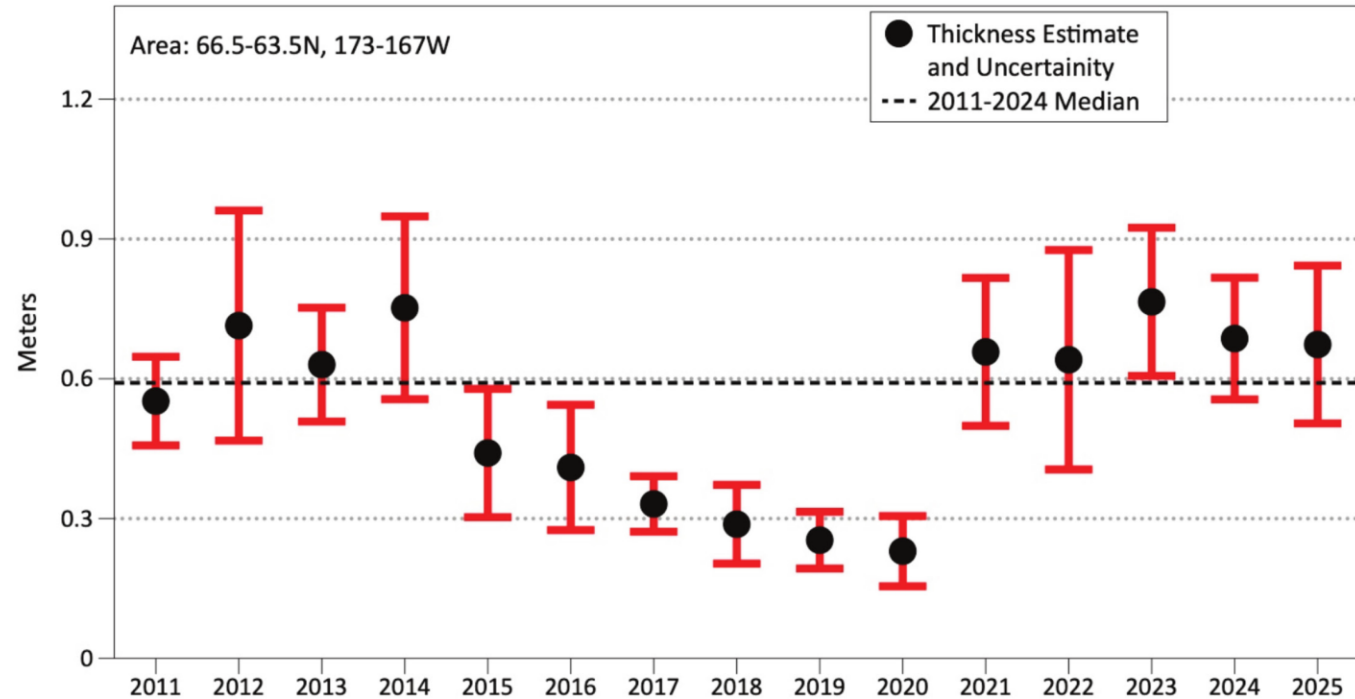
From [cpc.ncep.noaa.gov](https://cpc.ncep.noaa.gov)



## Winter (JFM) Bering Sea Ice Extent



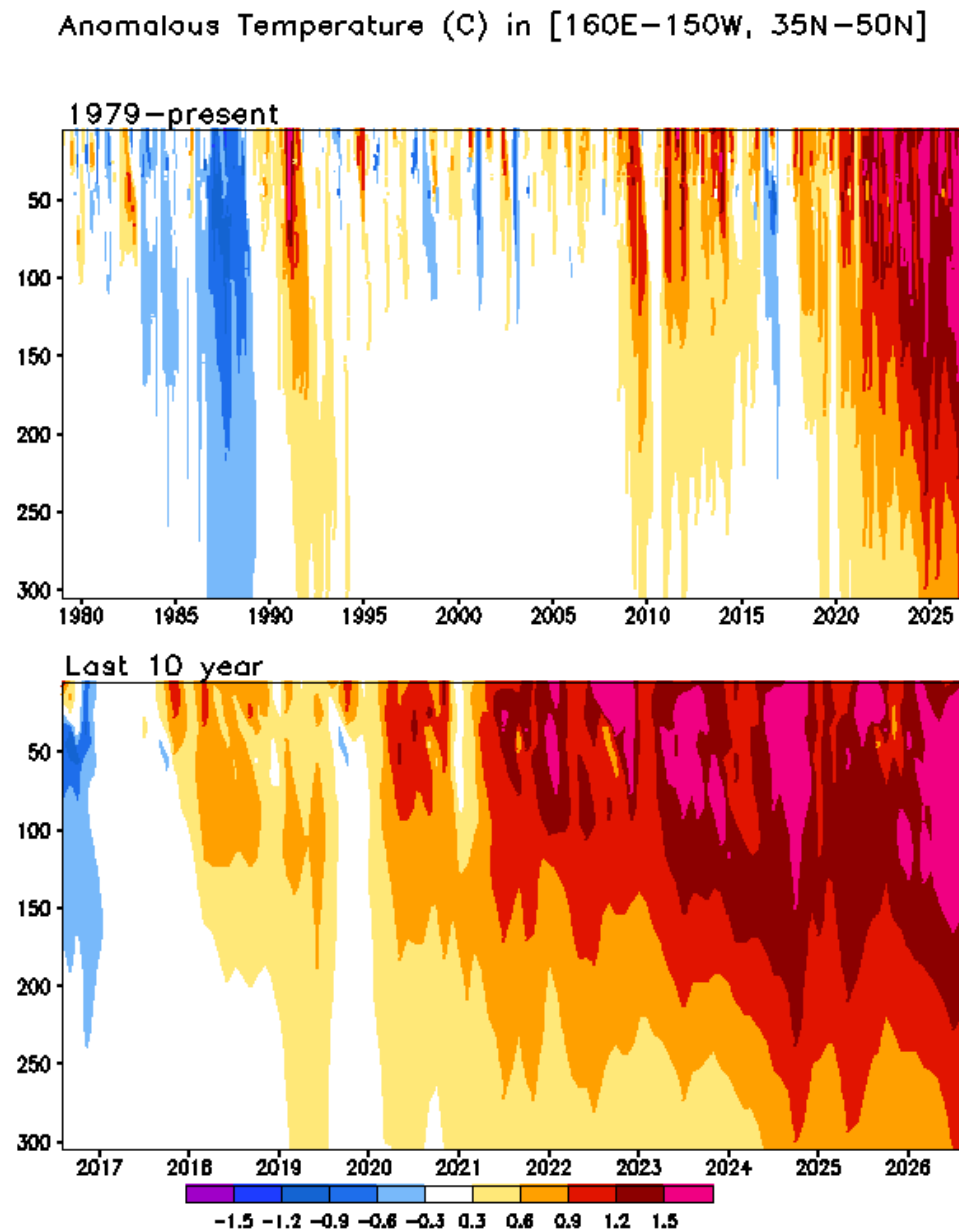
## March Sea Ice Thickness near the Bering Strait



Overland and Ballinger,  
*International Journal of Climatology*, 2025; 45:e70092  
<https://doi.org/10.1002/joc.70092>



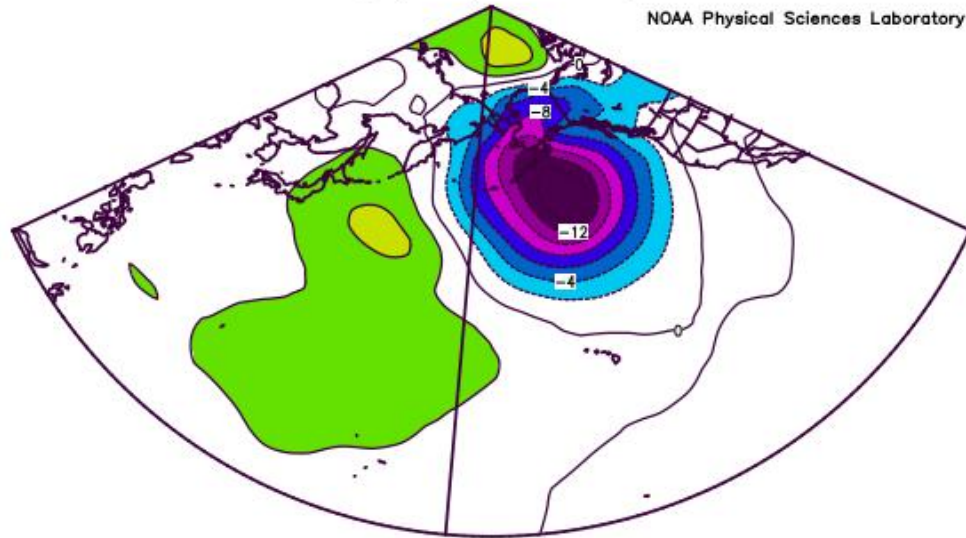
Warming of the upper 300m of the North Pacific has been extreme since 2021



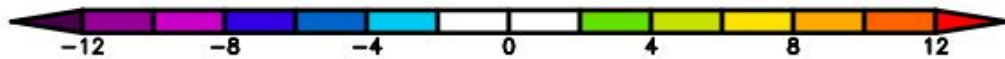
## Composite SLP anomalies for 2016

Sea Level Pressure (mb) Composite Anomaly 1991–2020 climo

NOAA Physical Sciences Laboratory



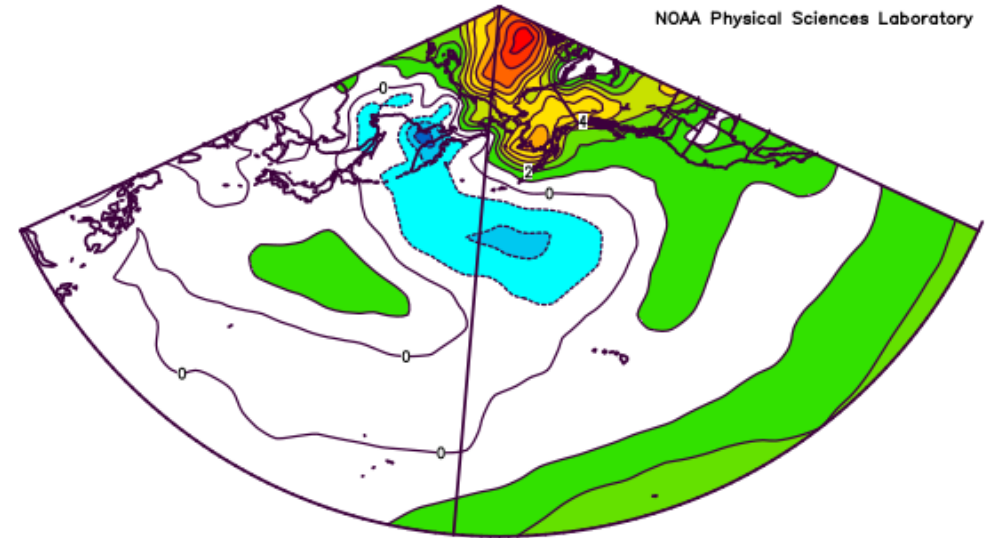
Jan to Mar: 2016



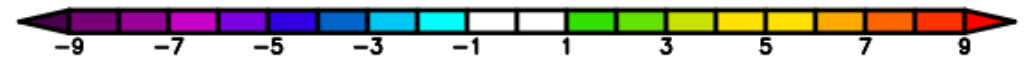
## Composite Surface Temperature Anomalies for 2016

Surface air (C) Composite Anomaly 1991–2020 climo

NOAA Physical Sciences Laboratory

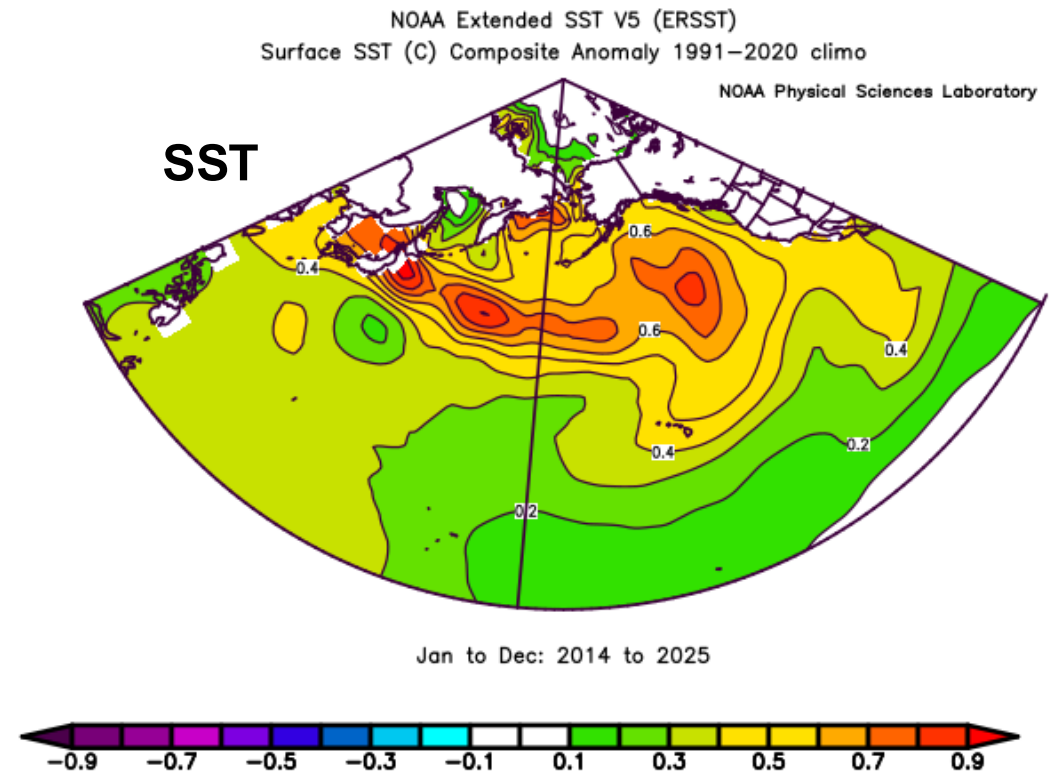
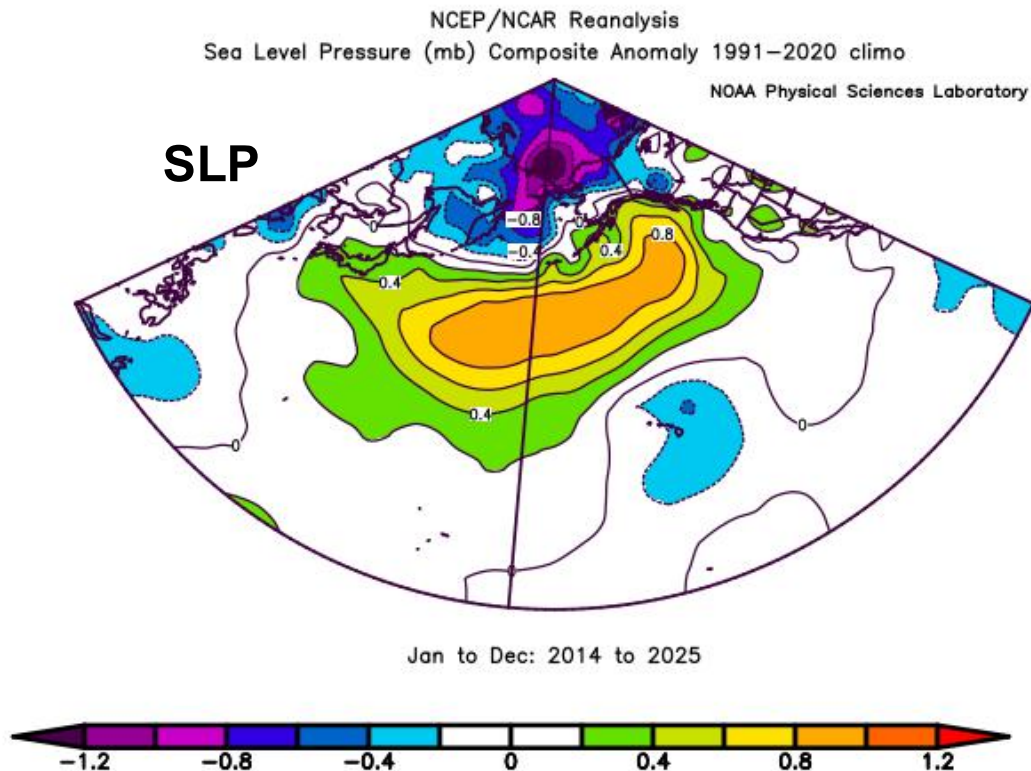


Jan to Mar: 2016



# SLP and SST anomalies for 2014-20205

- A weak Aleutian Low and a weak Bering Sea High, along with a very warm subarctic North Pacific



# Pacific Arctic Ecosystems

North Bering and Chukchi Sea Ice Loss  
and Ecosystem Transformation

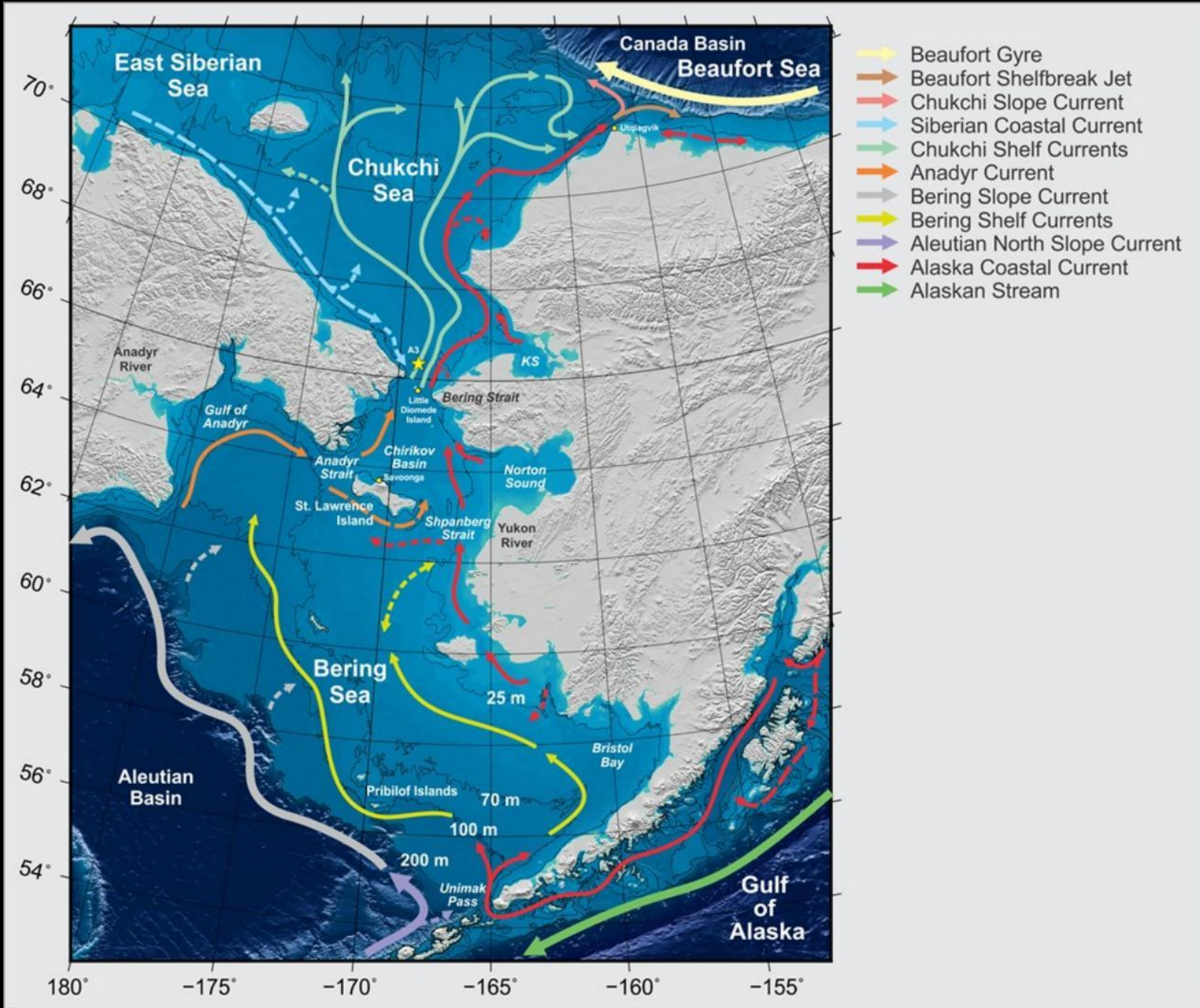
Kate Stafford  
Oregon State University

Seth Danielson  
University of Alaska Fairbanks

Sue E. Moore  
University of Washington

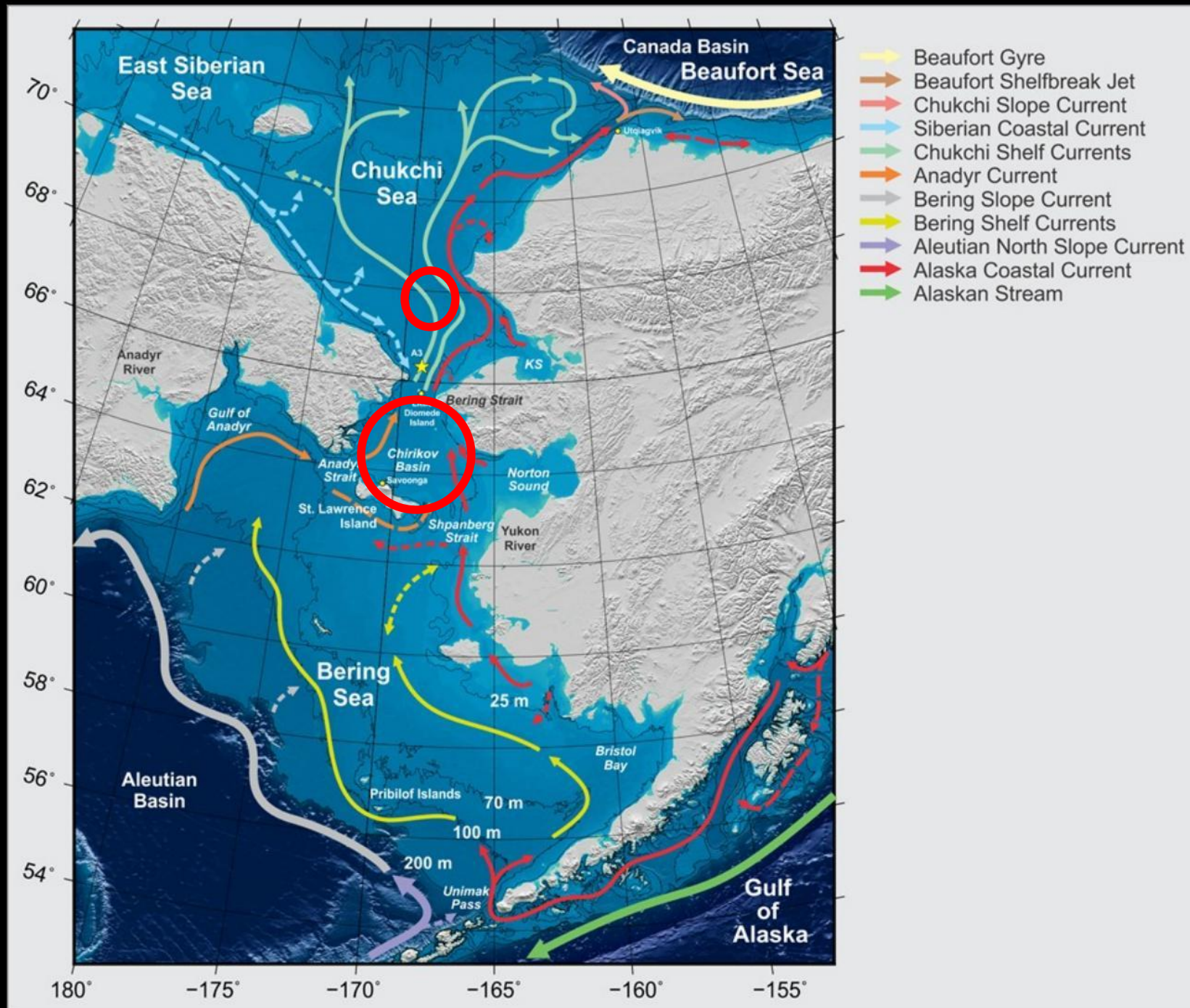
# Shallow shelf seas

- ~50 m depth
- Bering Strait 80 km wide
- CS formerly had multi-year ice
- BS annual sea ice
- Both seas highly productive

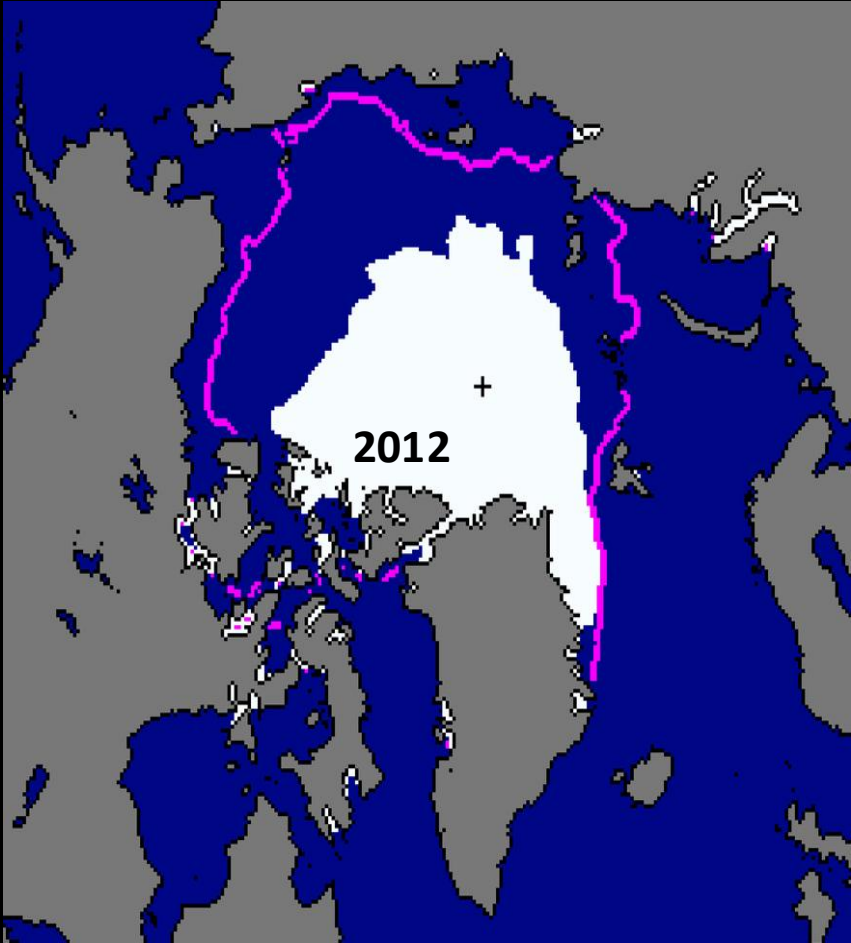


# Regional Circulation

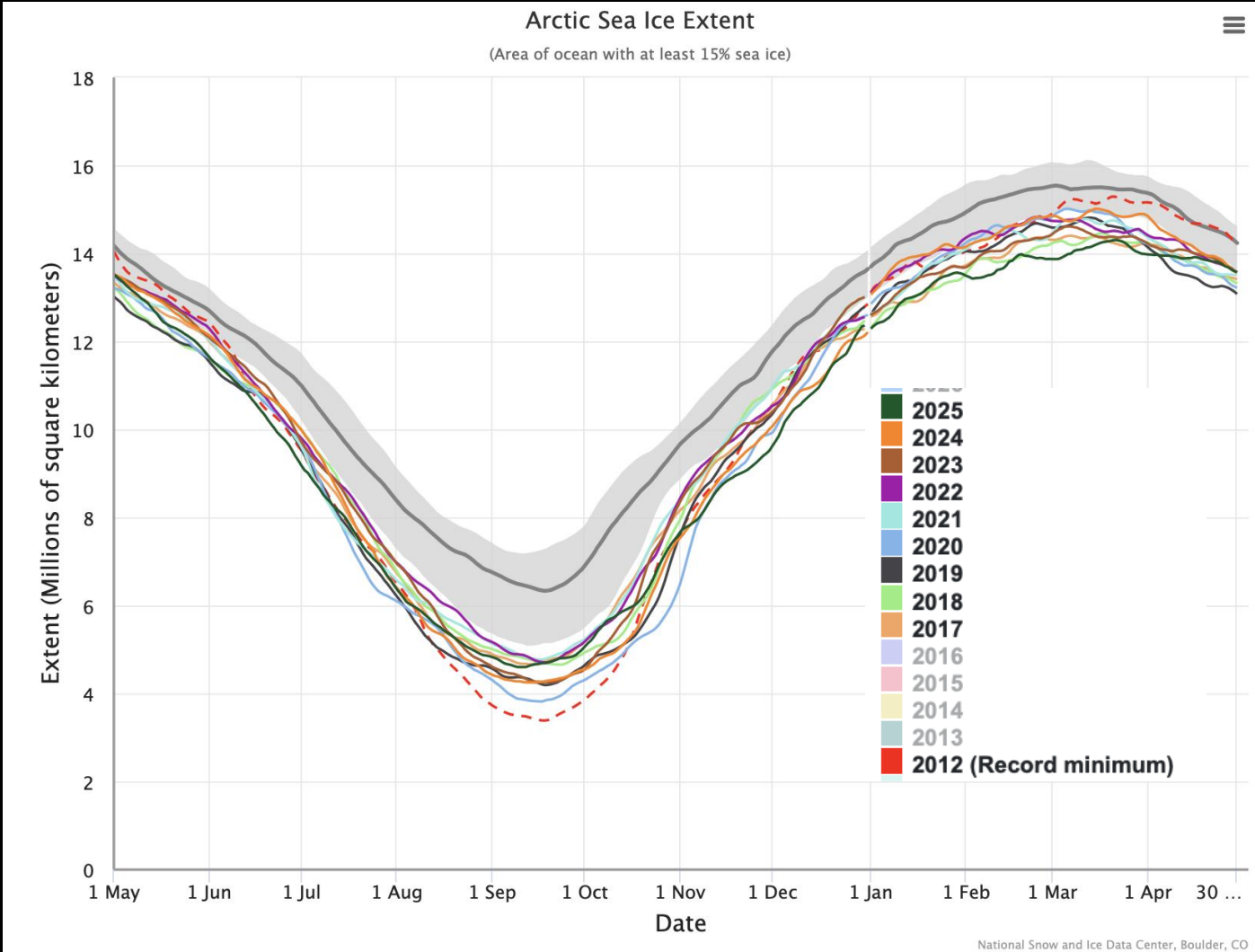
- Net flow northward
- Highly responsive to wind speed and direction
  - Sea ice is also highly responsive to these



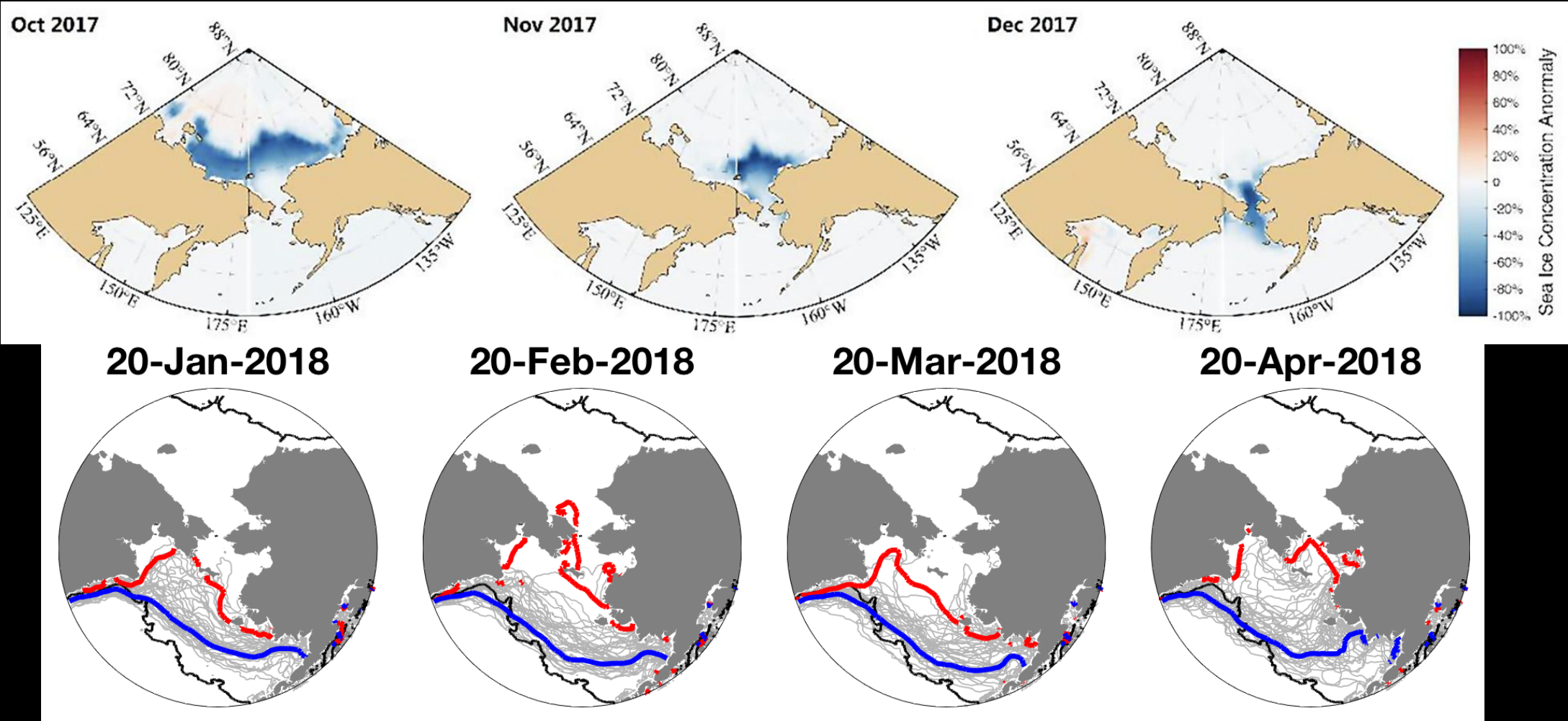
# SEA ICE Extent = 50 % Reduction in Surface Area



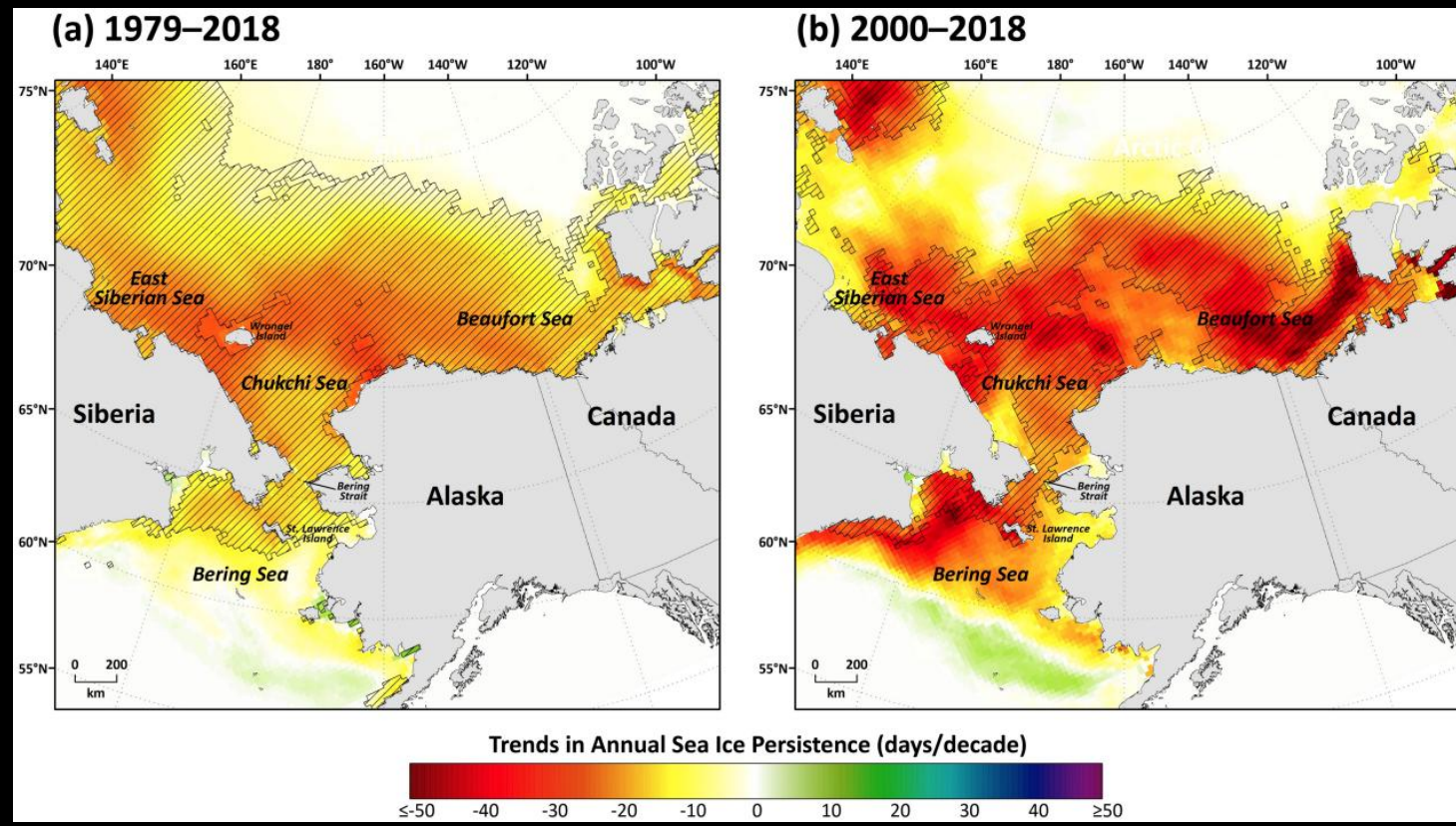
September median extent, 1980-90s



# Winter Retreat of the Leading Ice Edge



# Trends in Sea Ice Persistence



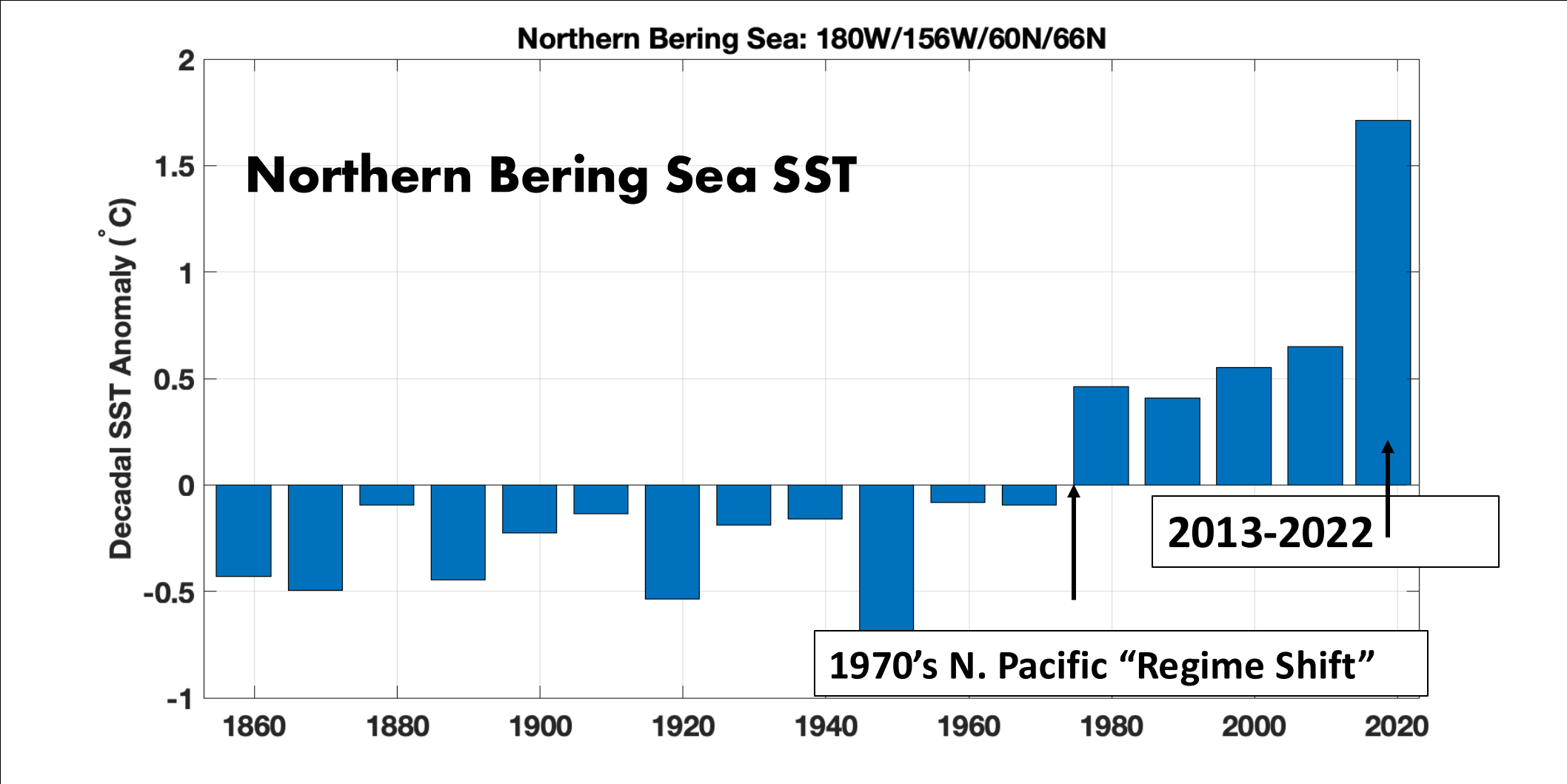
↑ **Bering Strait inflow**  
50%, since 2001

↑ Record-high **heat flux**  
in 2007 & 2015  
(Woodgate 2018)

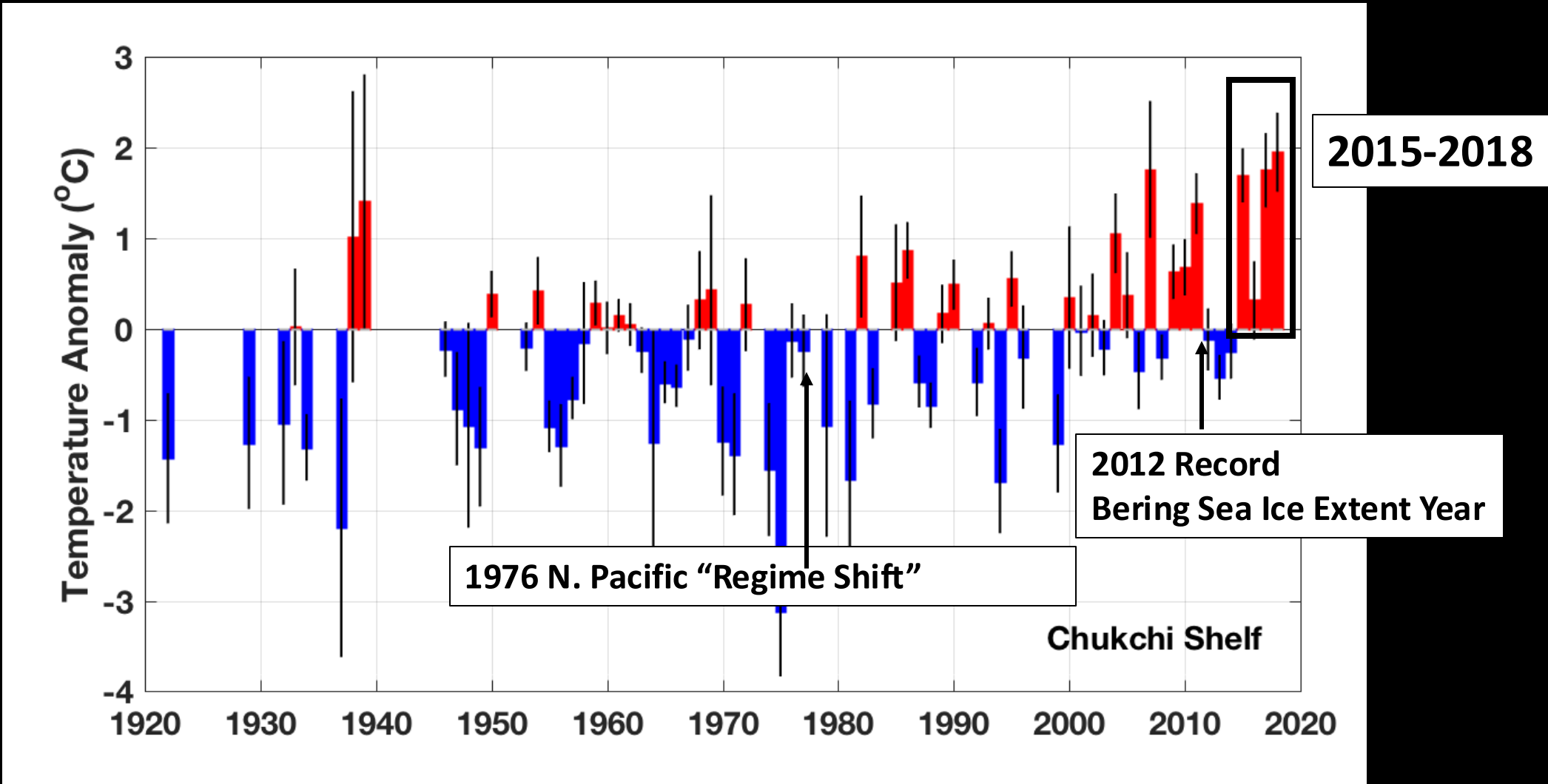
↑ Water-column **heat**  
2014-2018 (Danielson  
et al. 2020)

Courtesy of Karen Frey

# Sea Surface Temperature Anomaly Year-round, by Decade 1854-2022



# 1922-2018 Chukchi Shelf July to October Ocean Temperature Anomalies

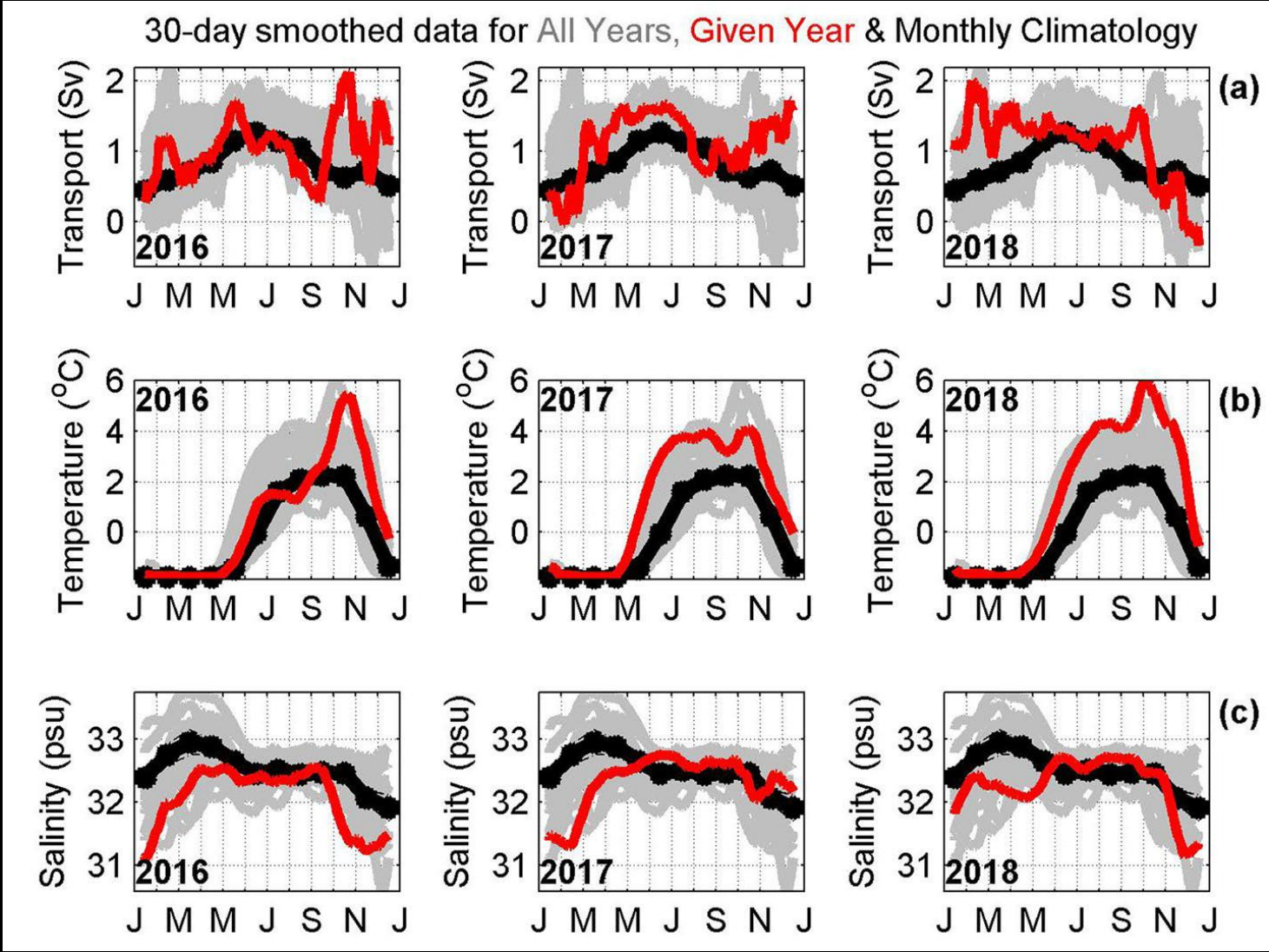


# Bering Strait changes 2016-2018

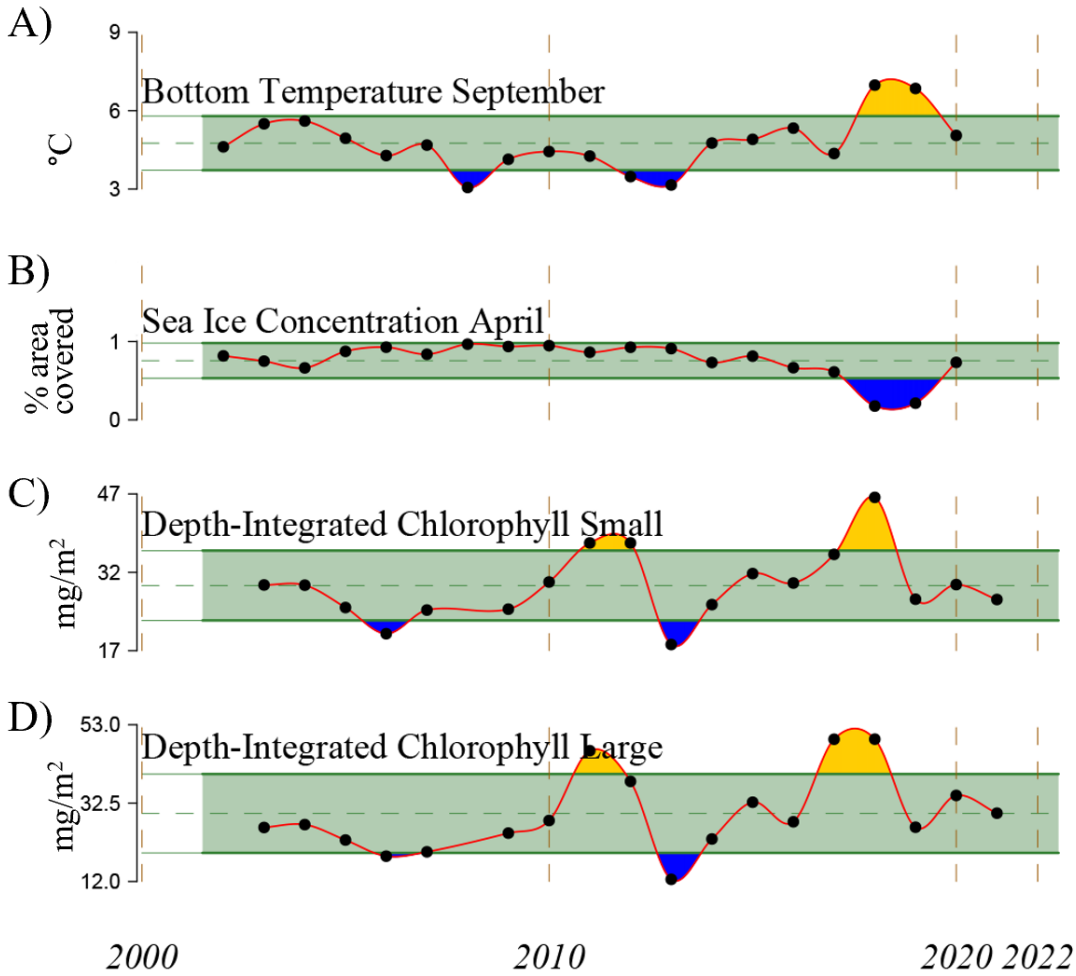
Increased transport

Increased temp

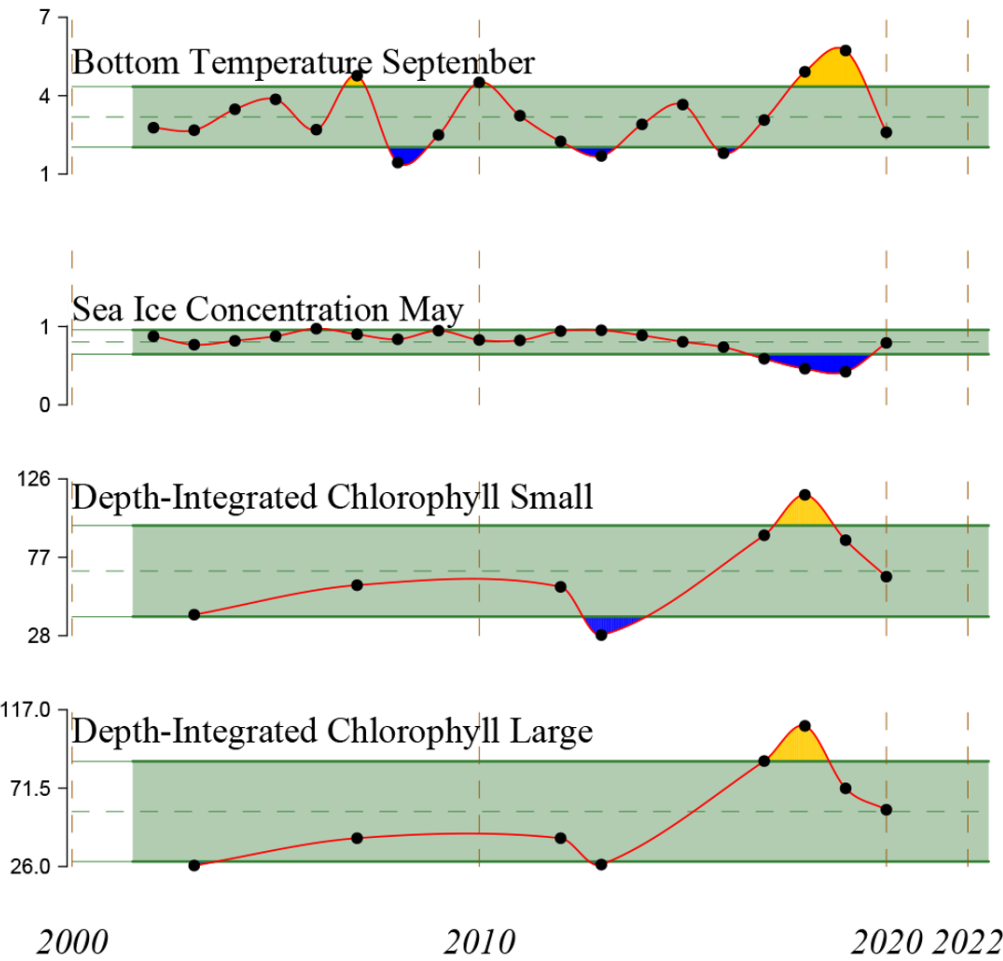
Decreased salinity



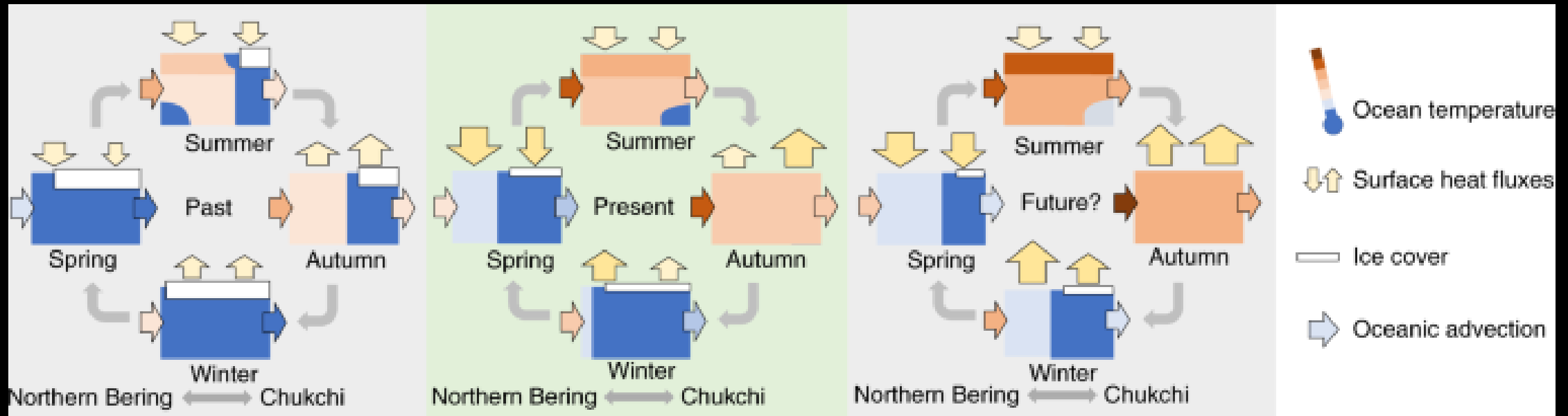
NORTHERN BERING SEA



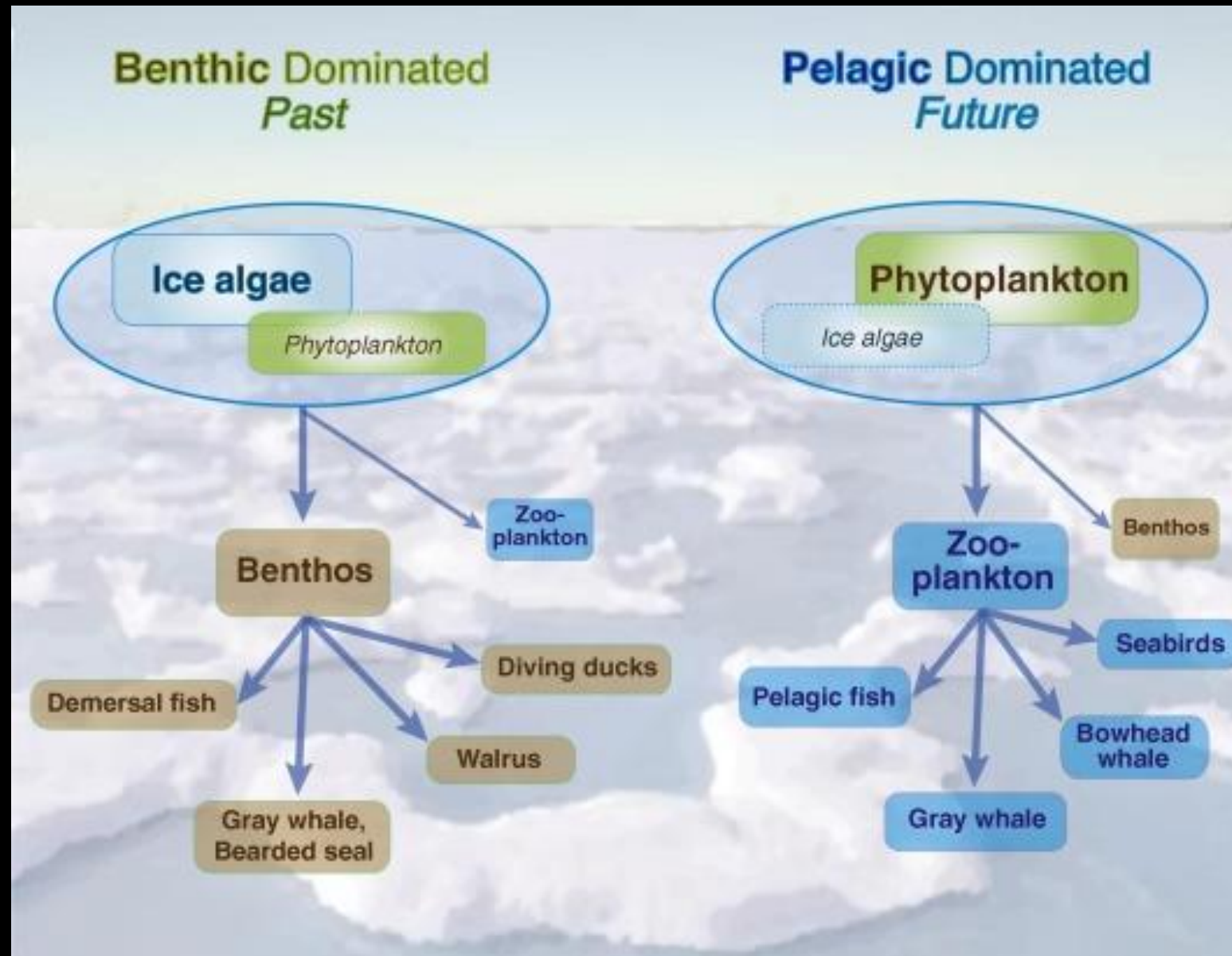
CHUKCHI SEA



# Environmental changes and consequences for the ecosystem



- Altered timing and magnitude of spring-ice-associated phytoplankton and zooplankton blooms
- Expansion of subarctic species distributions northwards
- New predation pressure on Arctic pelagic and benthic communities
- Accelerated coastal erosion and delivery of terrestrial carbon to marine domain



# Time series trends in benthic prey populations in the northern Bering and Chukchi Seas

Jacqueline M. Grebmeier<sup>1</sup>, Lee W. Cooper<sup>1</sup>, Brian P. Marx<sup>1</sup>, and Sue E. Moore<sup>2</sup>

<sup>1</sup>Chesapeake Biological Laboratory, University of Maryland Center for Environmental Science, Solomons, Maryland, USA,

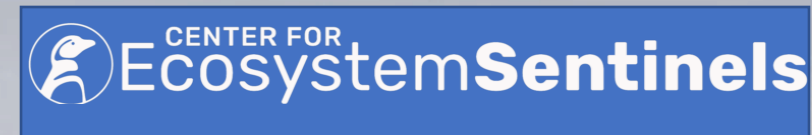
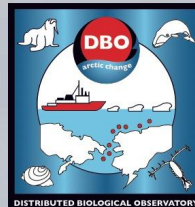
<sup>2</sup>Department of Biology, University of Washington, Seattle, Washington, USA

**Range-Wide Gray Whale Science Symposium**

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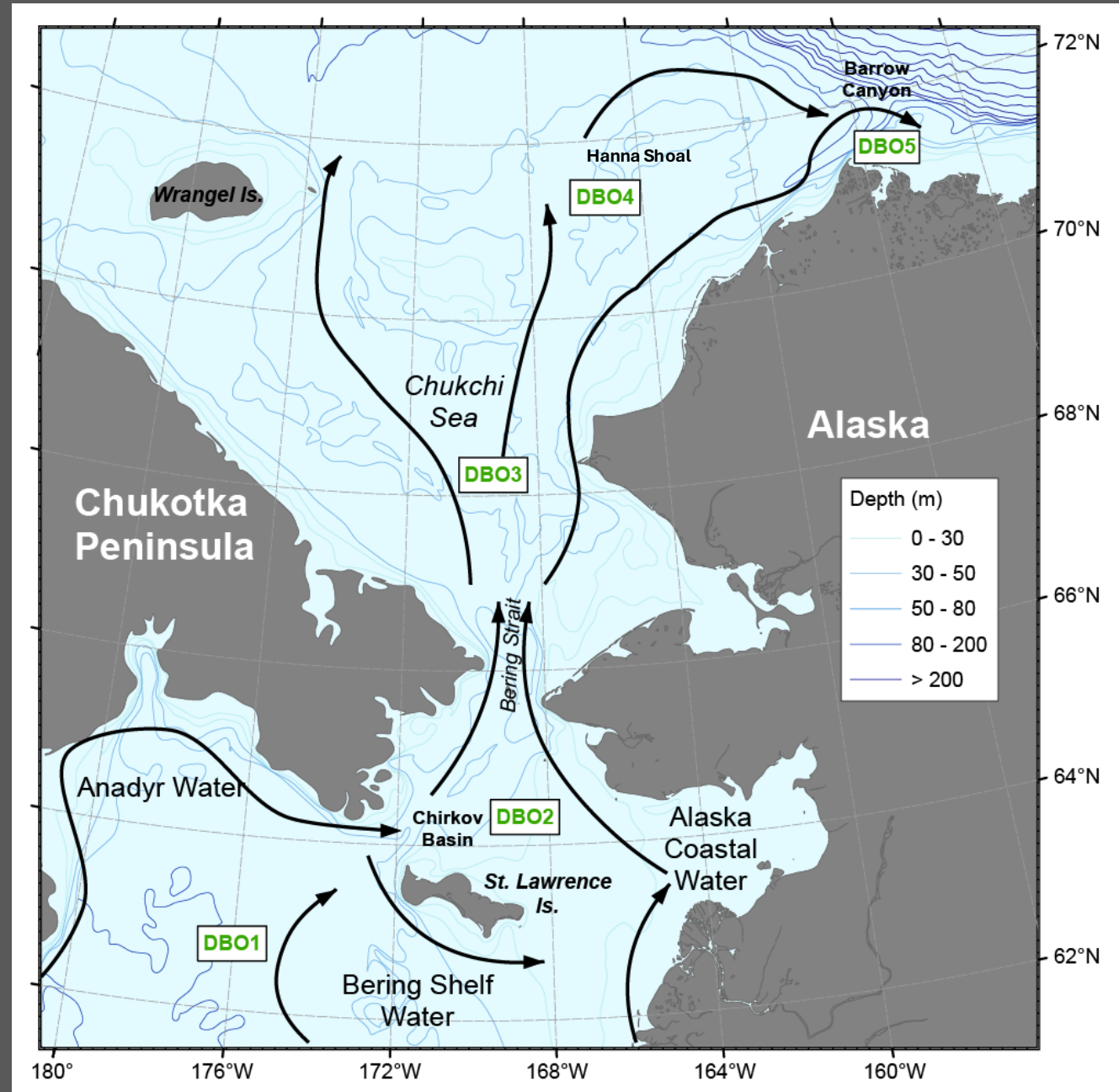
Hartfield Marine Science Center

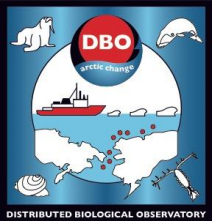
Newport, Oregon



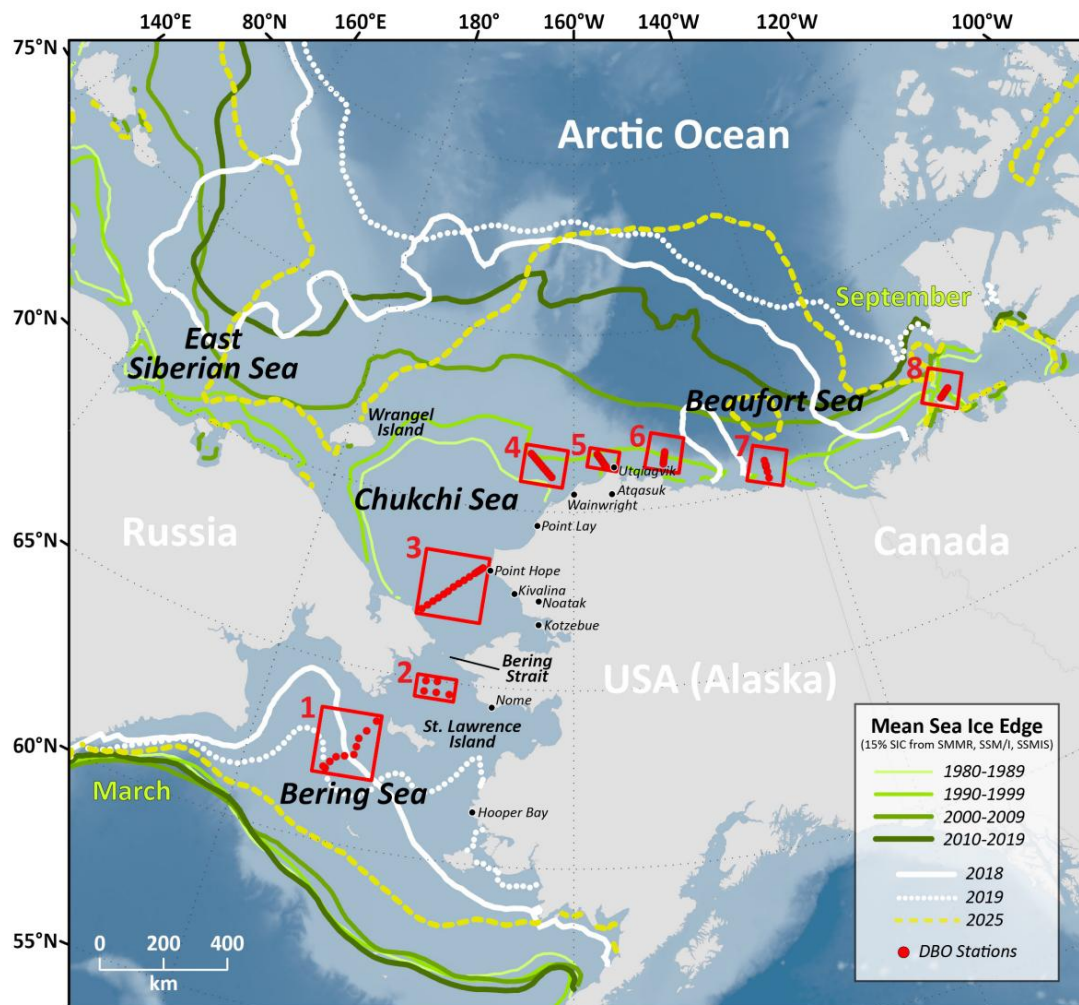
# Outline of Talk

- Regional Circulation: net flow northward; highly responsive to wind speed & direction
- Distributed Biological Observatory (DBO)
- Sea ice coverage and change
- Water column production
- Bottom water temperatures
- Benthic macrofaunal biomass and composition
- Temporal and spatial changes in amphipod prey for gray whales
- Summary





# The Distributed Biological Observatory (DBO): Linking Physics to Biology

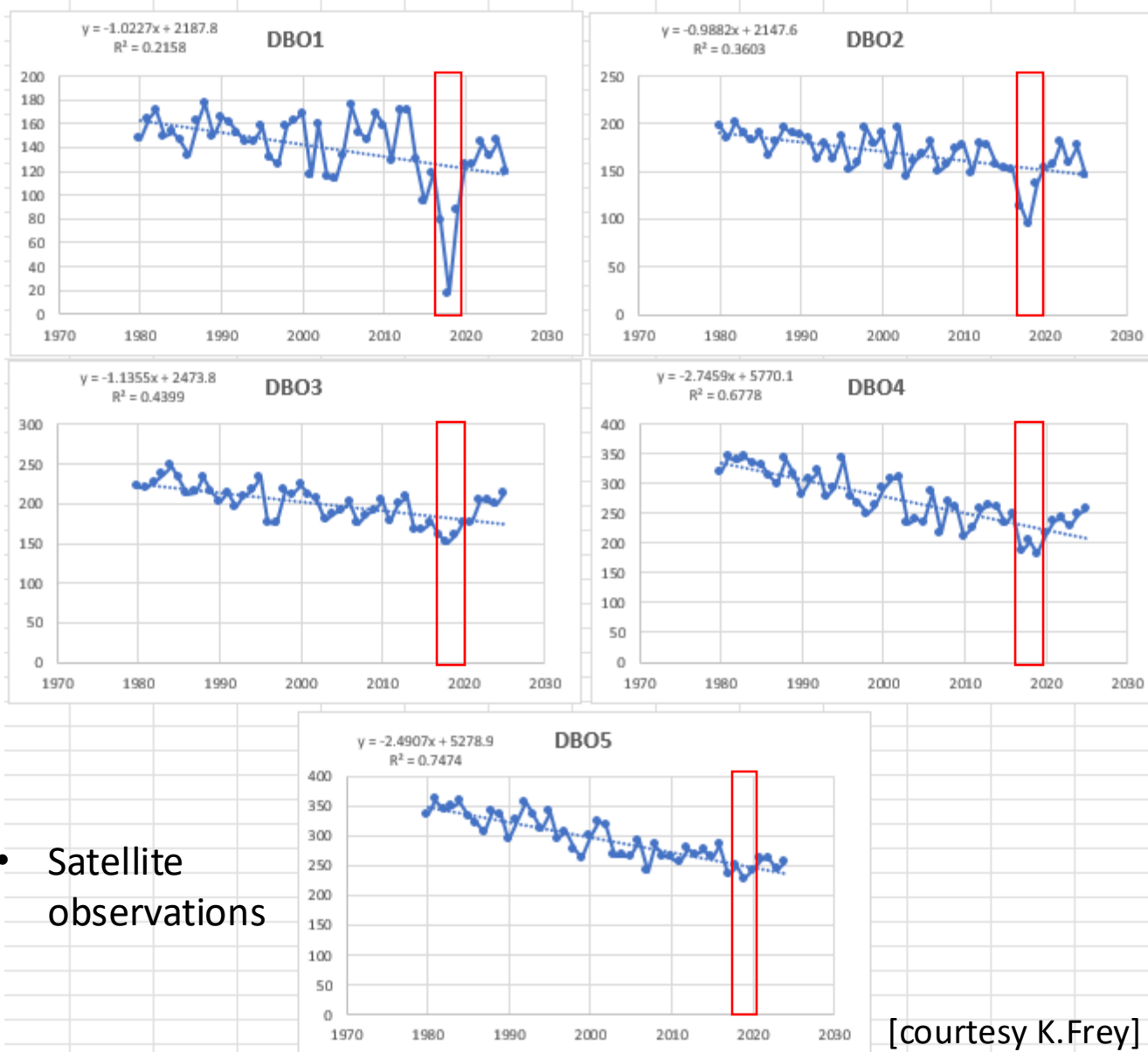


- **DBO serves as a change detection array** for consistent monitoring of biophysical responses to environmental drivers in the Pacific Arctic (P-DBO)
- **Focus on biological hotspots & standardized sampling** designed to detect regional changes in Arctic marine ecosystems
- **Initiated in 2010 with progress reviewed twice a year** at Arctic Science Summit week and autumn Pacific Arctic Group meetings
- **Collaborate and share platforms** with the other field programs, both U.S. and international partners
- **Ongoing efforts with international cooperation** for implementation of Atlantic, Baffin Bay/Davis Strait, and Siberian DBOs for a Pan-Arctic DBO network

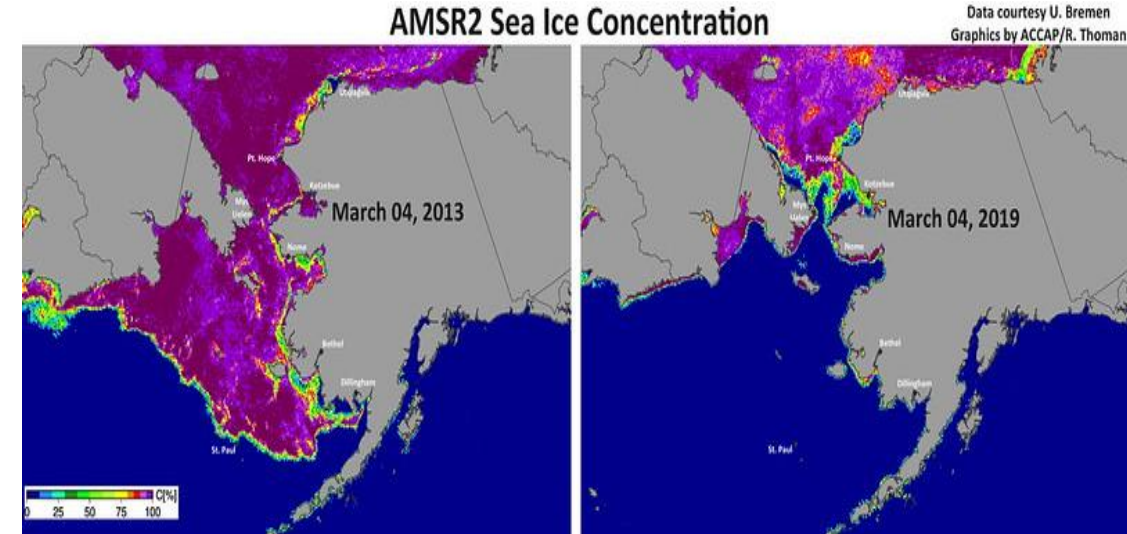


# Pacific Arctic Ecosystem Changes: Reduced Sea Ice and More Open Water

Sea ice persistence over time

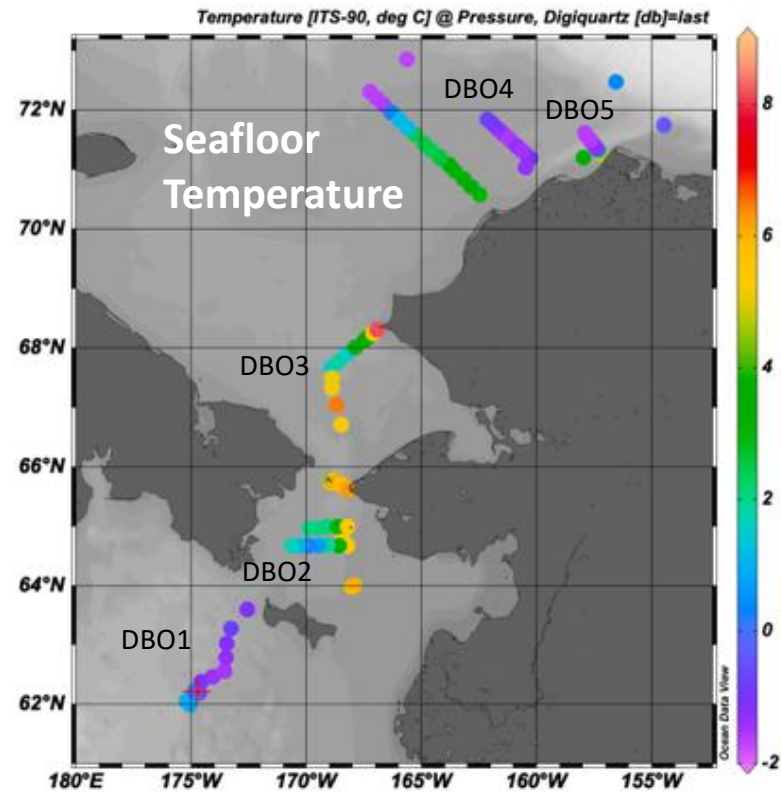


- Most extreme reduction of sea ice in winter of 2019 compared to 2013



- Highest reduction sea ice in DBO1 and DBO2 in the northern Bering Sea (left red boxes)
- Diminished in pattern as move northward, but upward trend in last few years
- Bering Strait inflow + 50%, since 2001 with record-high heat flux in 2007 & 2015 (Woodgate 2018)
- Water-column heat high 2014-2018 (Danielson et al. 2020)

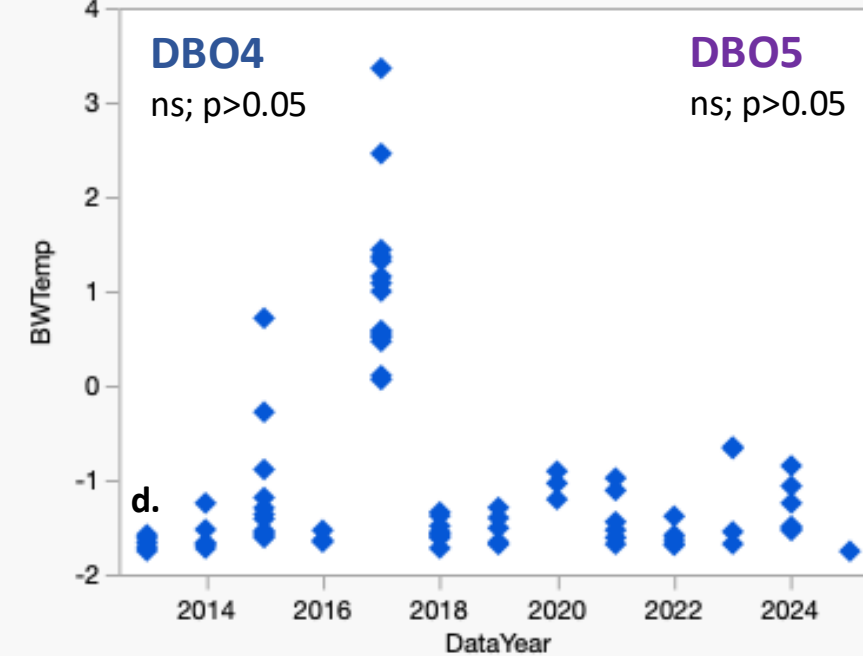
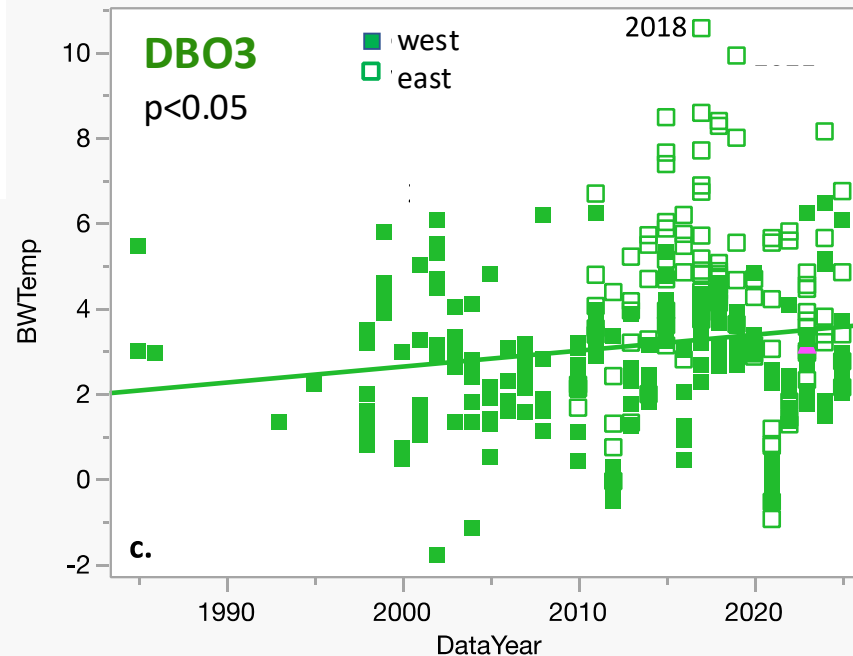
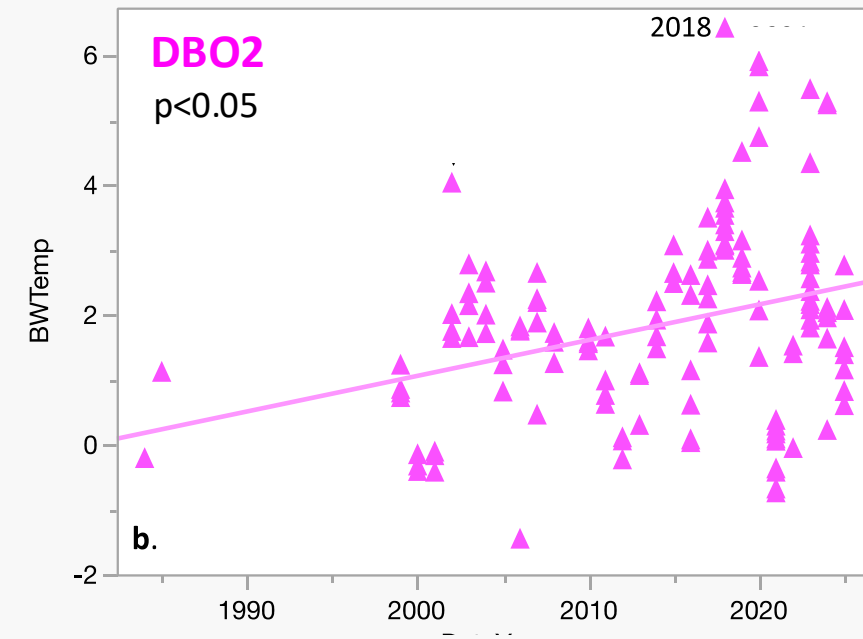
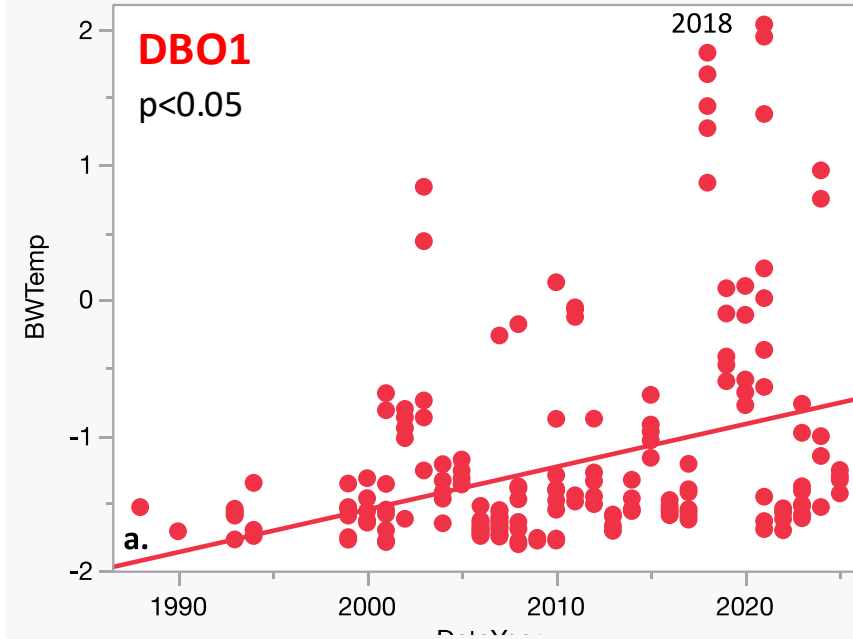
# Bottom Water Temperatures (°C): DBO1-4



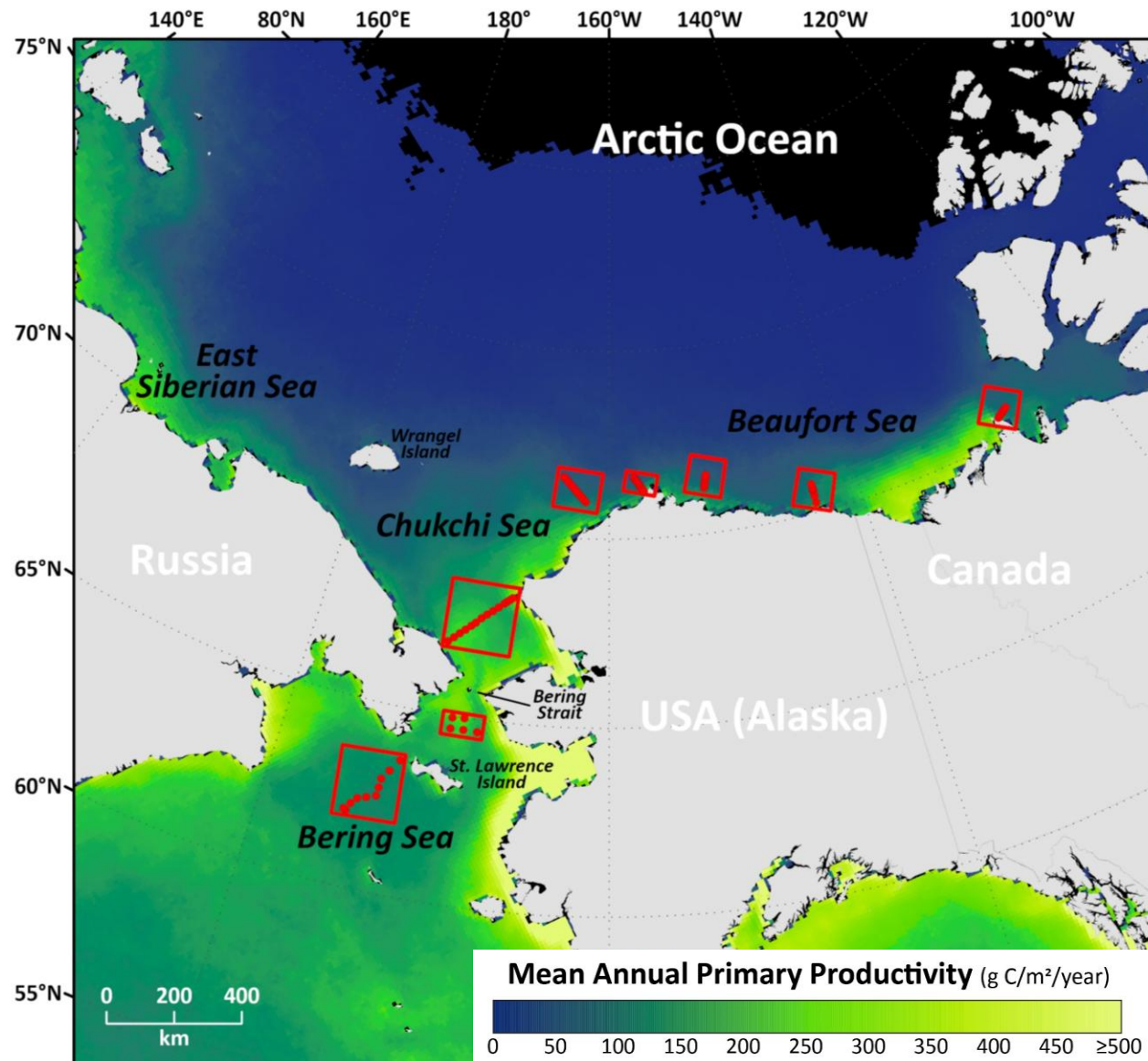
[SKQ24-Seth Danielson]

- Significant increase bottom water temperatures at DBO1, DBO2, and DBO3
- No significant trend at DBO4 or DBO5

[Cooper and Grebmeier]

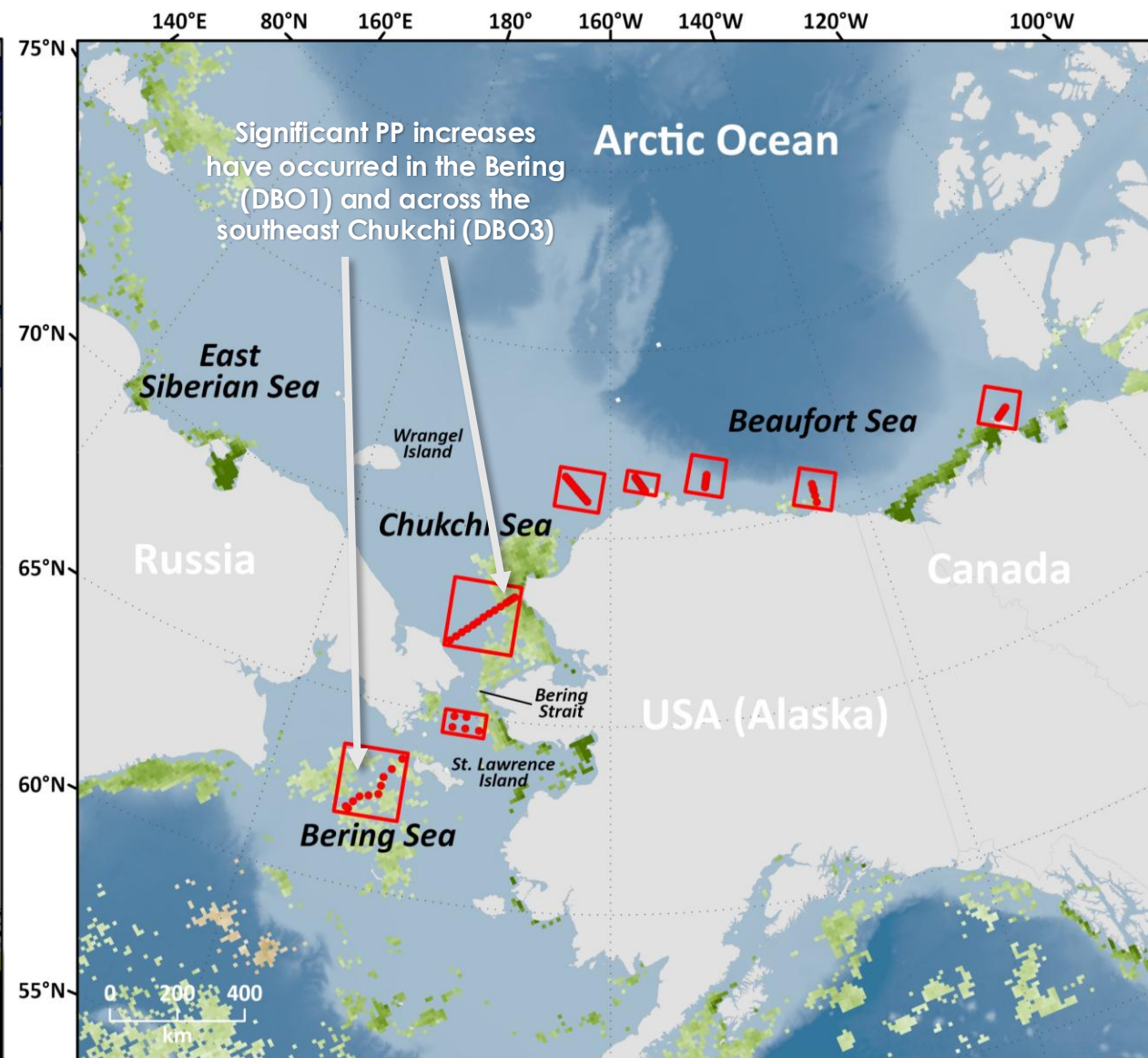


## Mean Annual Primary Productivity (2003-2025)

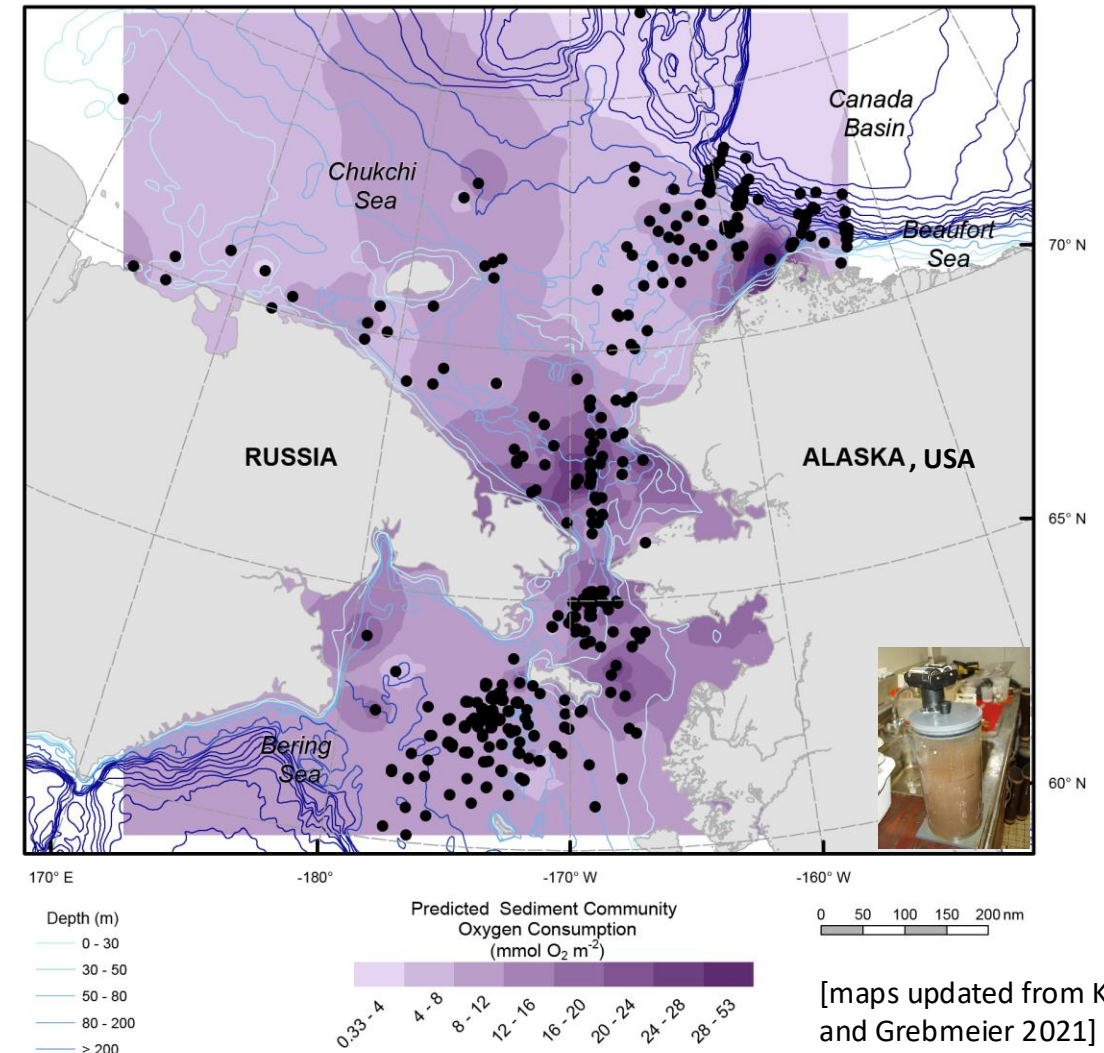
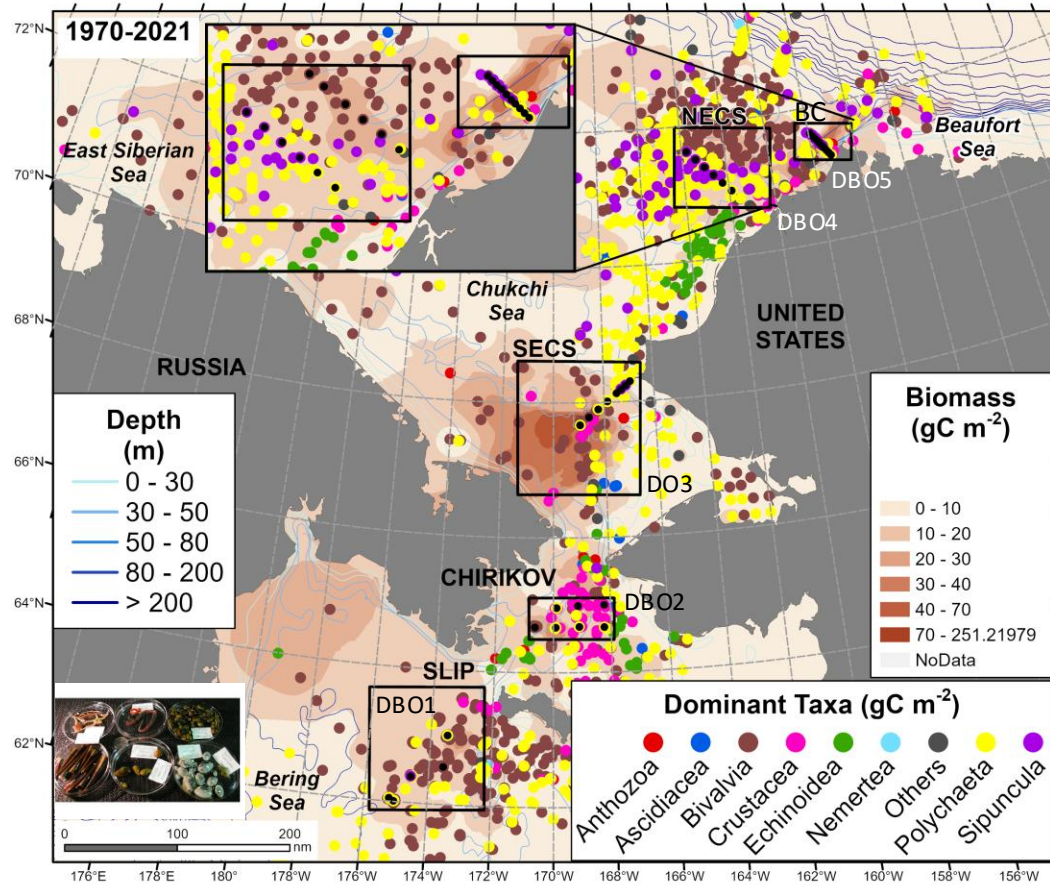


## Trends in Annual Primary Productivity (2003-2025)

*\*Only those trends that are significant ( $p < 0.05$ ) are shown*



# Distribution of benthic biomass and dominant fauna and carbon supply to the benthos in the Pacific Arctic



[maps updated from Kedra and Grebmeier 2021]

- Macrofaunal biomass increasing along a latitudinal gradient from northern Bering Sea to SE Chukchi Sea
- Hotspot benthic areas in black boxes sampled as part of Distributed Biological Observatory (DBO) effort

- Sediment community oxygen consumption as indicator of carbon supply to the benthos

Gray whales are the only species that suction feed on benthic infauna (e.g., amphipods), but they also feed on a variety of epifauna (e.g., mysids, cumaceans, crab larvae) and zooplankton (e.g., krill) prey =

## Opportunistic Foragers



Amphipod

Gray whales appear to feed on both in the Alaskan Arctic



Krill

- Can feed on krill at sea water surface and near sediments



Mud plumes from benthic feeding

Amy Willoughby  
NOAA/NMFS/AFSC/MML  
NMFS Permit No. 20465  
Funded by BOEM (IA Contract No. M17PG00031)



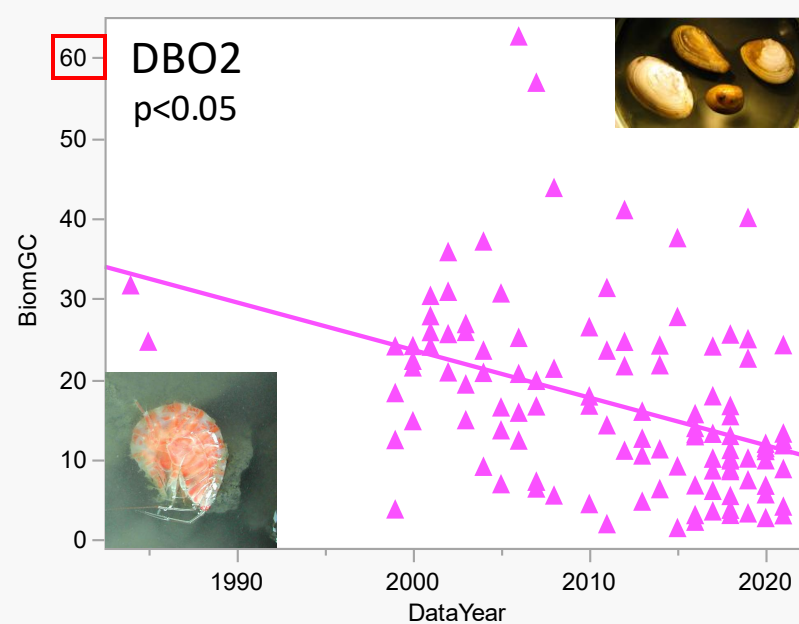
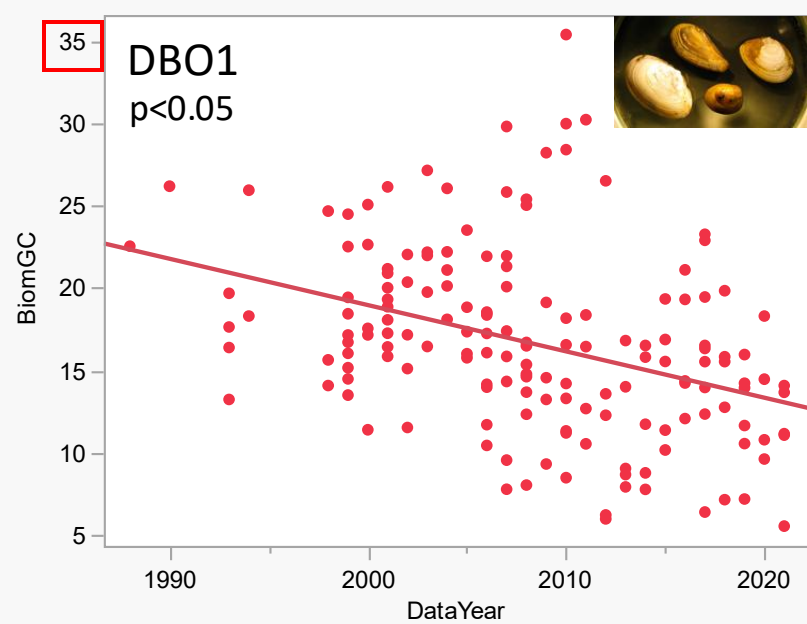
240723 005617.0 I



Filter feeding surface aggregation of krill  
[Photo: Kate Stafford]

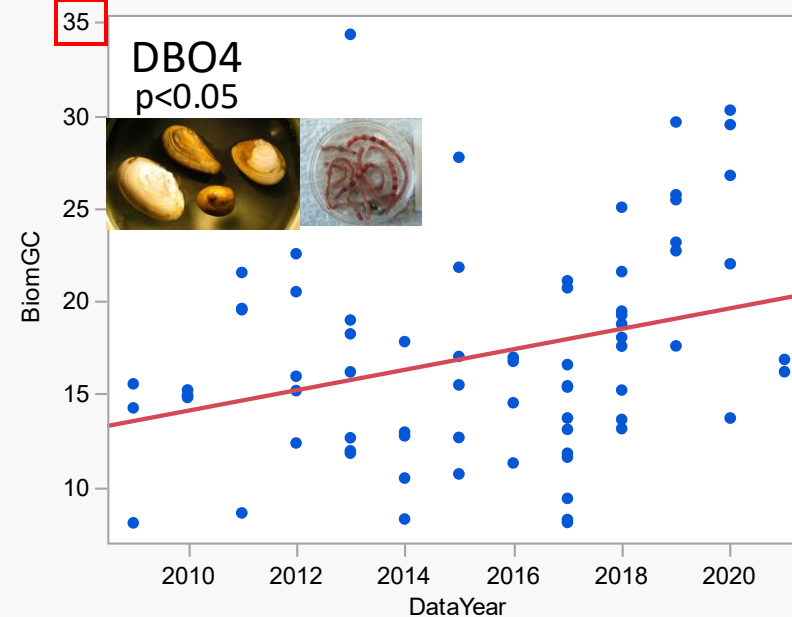
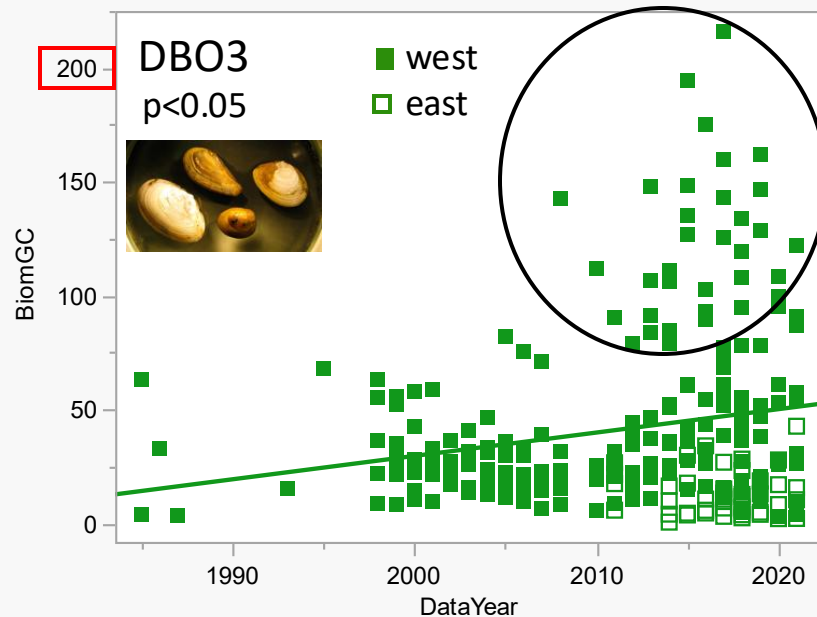
# Macrofauna time series benthic biomass in DBO1-DBO4

Northern  
Bering  
Sea



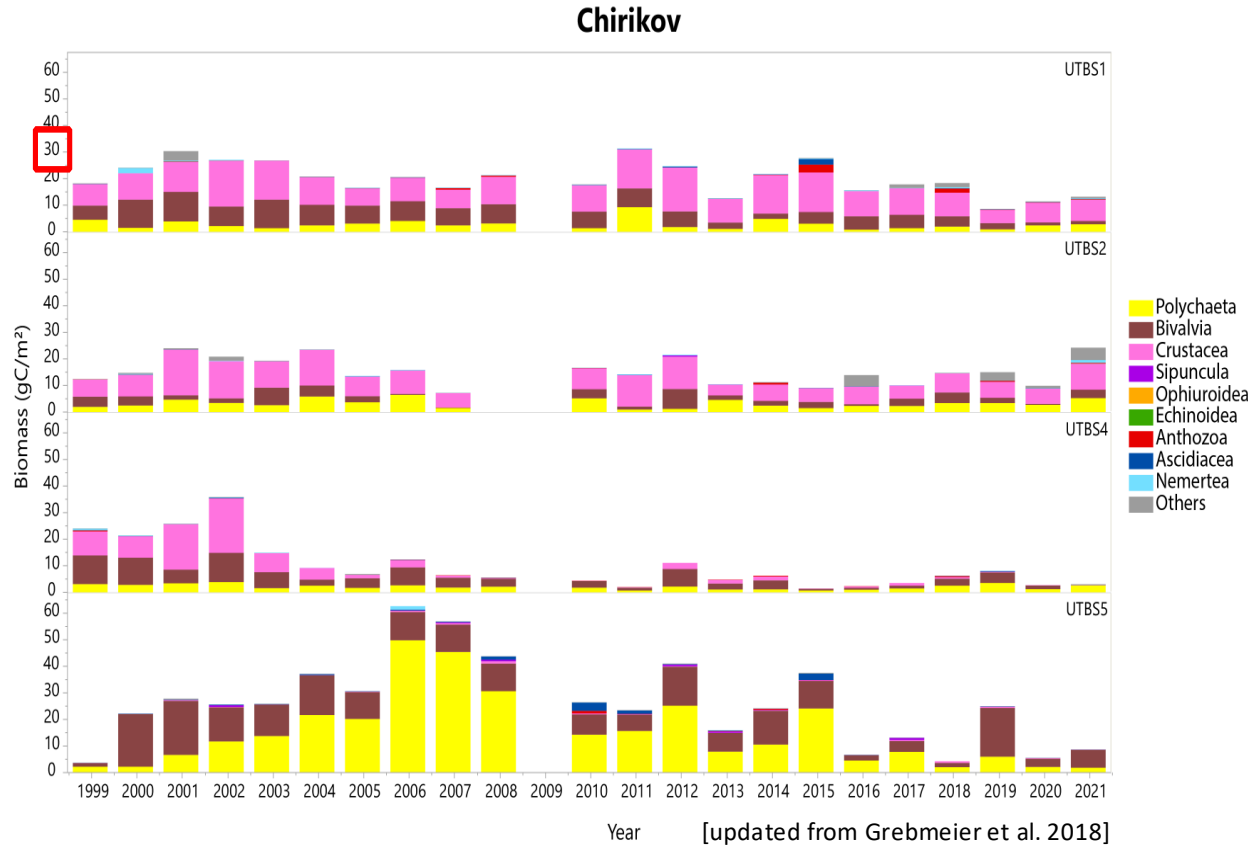
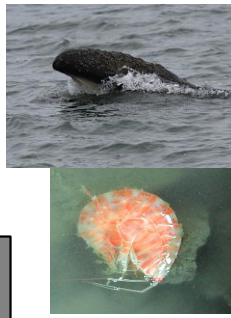
- Significant decline in benthic biomass at stations in the northern Bering Sea
- Significant increase in benthic biomass at stations north of Bering Strait in the SE Chukchi Sea (DBO3) and NE Chukchi Sea (DBO4)

Chukchi  
Sea

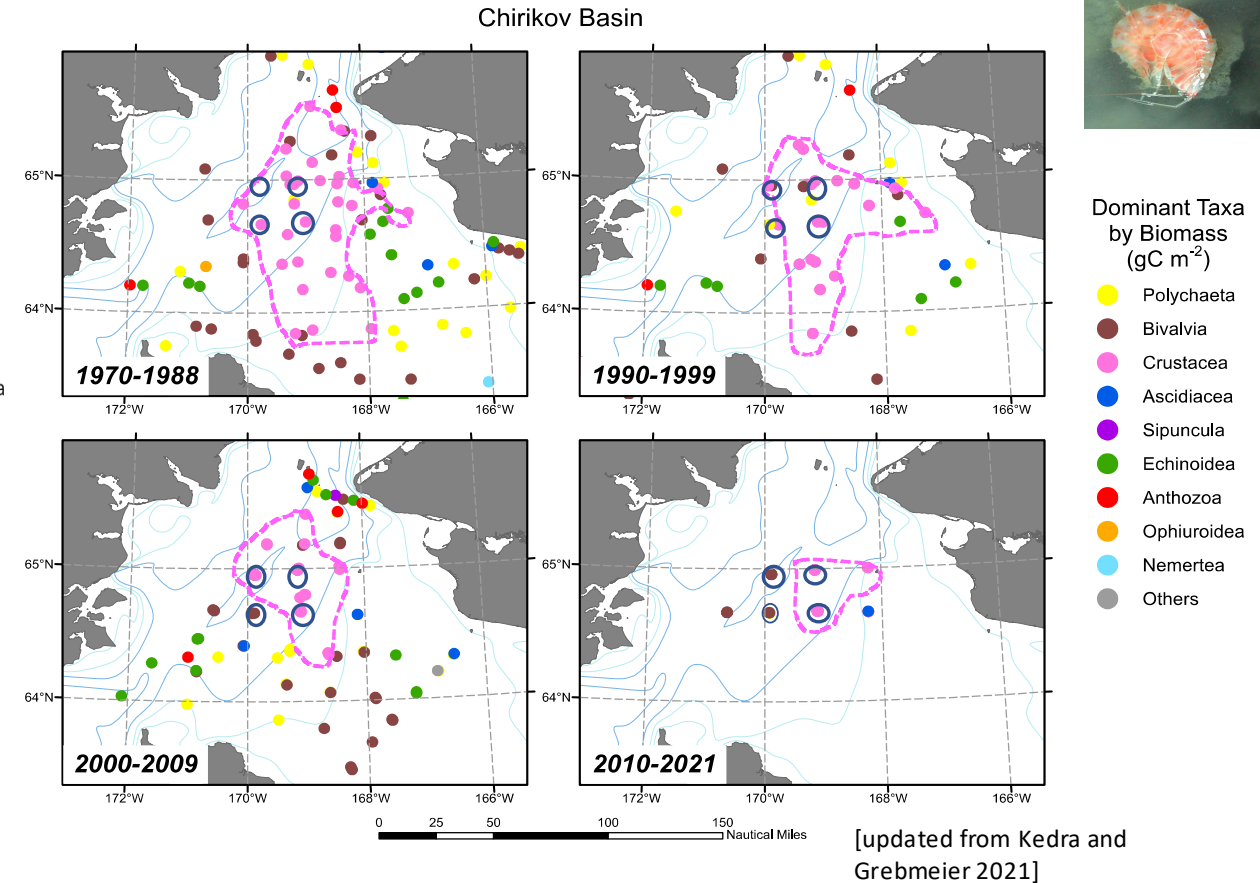


- Dominant macrofaunal biomass are bivalves DBO1, 3, and 4 and crustacean amphipods and bivalves in DBO2; polychaetes also 2<sup>nd</sup> dominant in DBO4

# DBO2 region-Decadal spatial contraction of benthic amphipod biomass



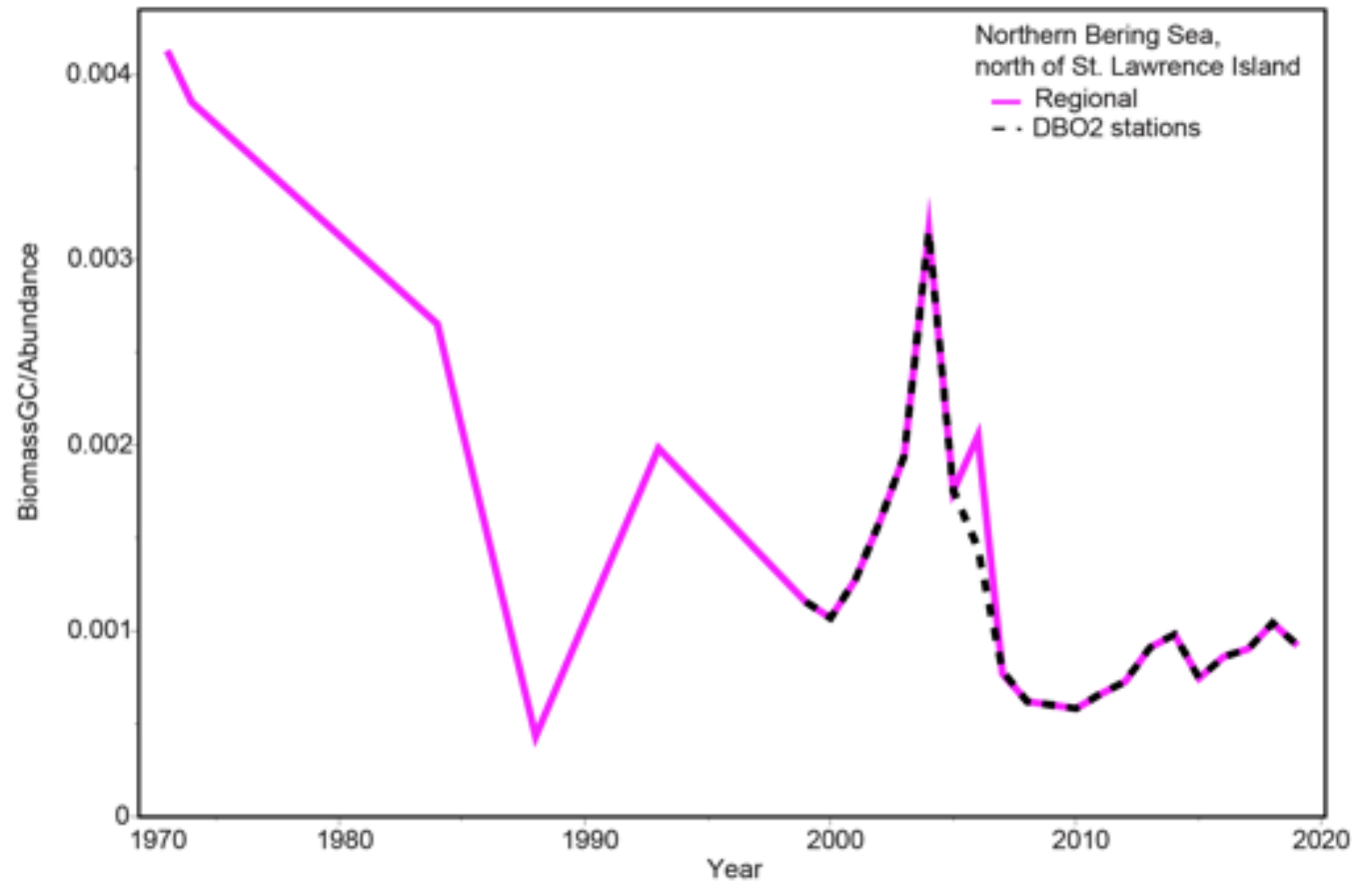
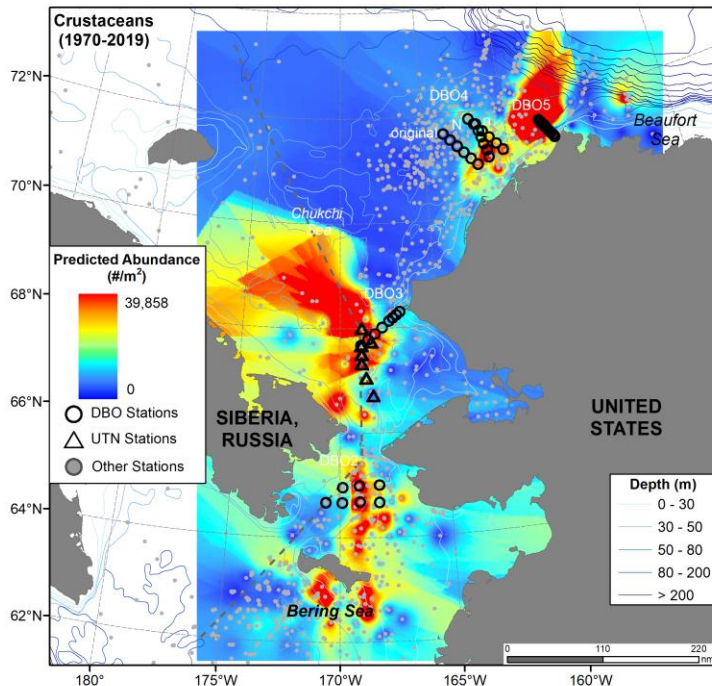
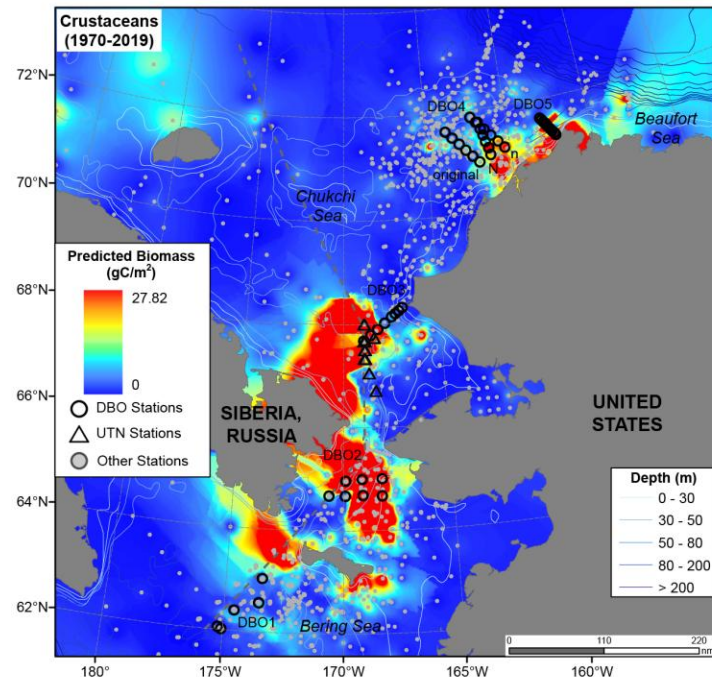
- Decline in crustacean amphipods in the Chirikov Basin at time series sites
- Western two time series sites changed from amphipods to bivalves and polychaetes over time, only eastern sites currently remain with amphipods



- Former main gray whale feeding area in the Chirikov Basin
- Spatial contraction and decline in amphipod biomass over decades

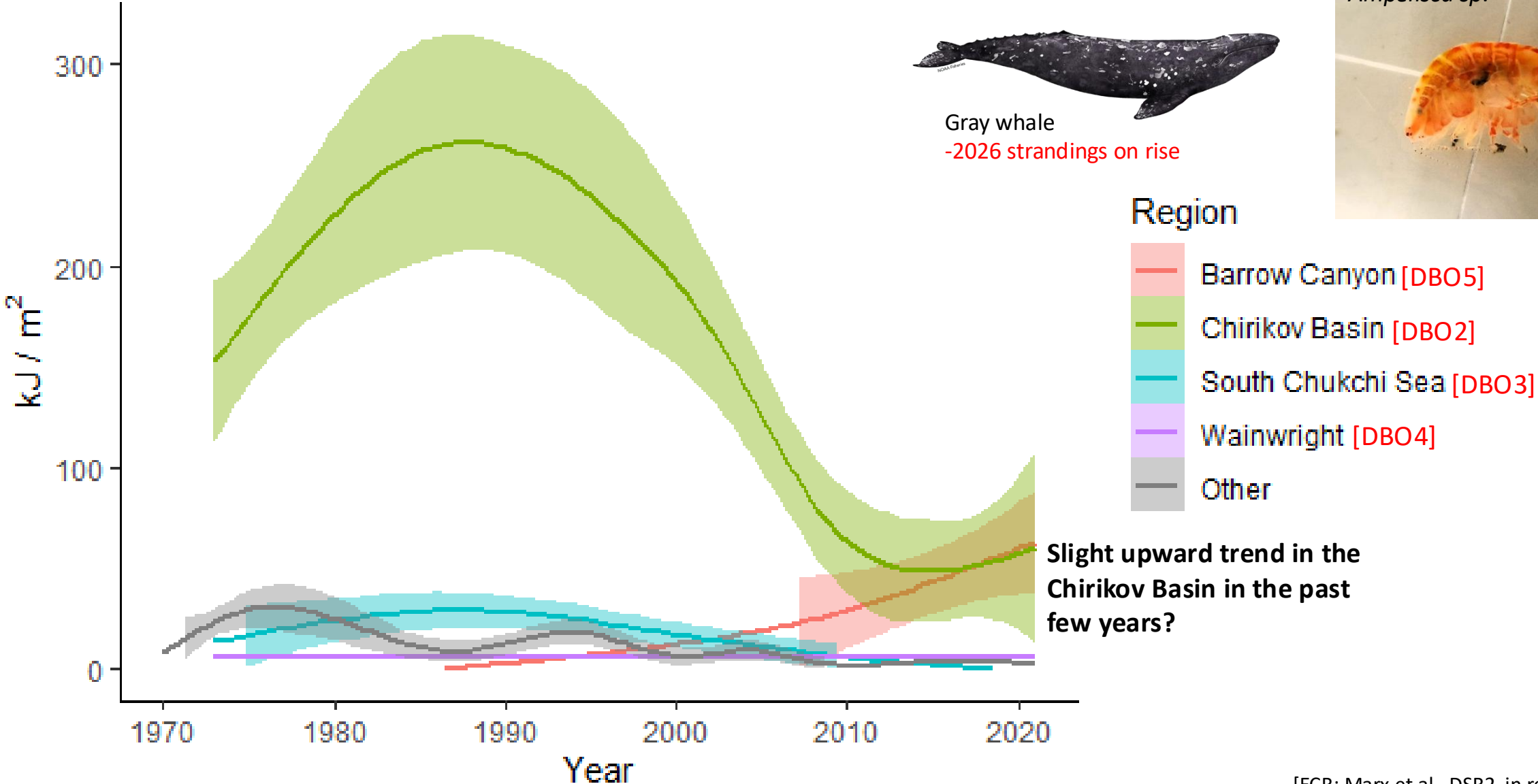
# Benthic amphipod population time series

- Time series **composite of crustacean biomass** (gC/m<sup>2</sup>), dominated by amphipods (top left) and **abundance** (no/m<sup>2</sup>) bottom right
- **Ratio of gC biomass to abundance (B/A)** represents per capita decline indicative of trend to smaller size of amphipods



# Trends in ampeliscid energy density using Generalized Additive Model (GAM)

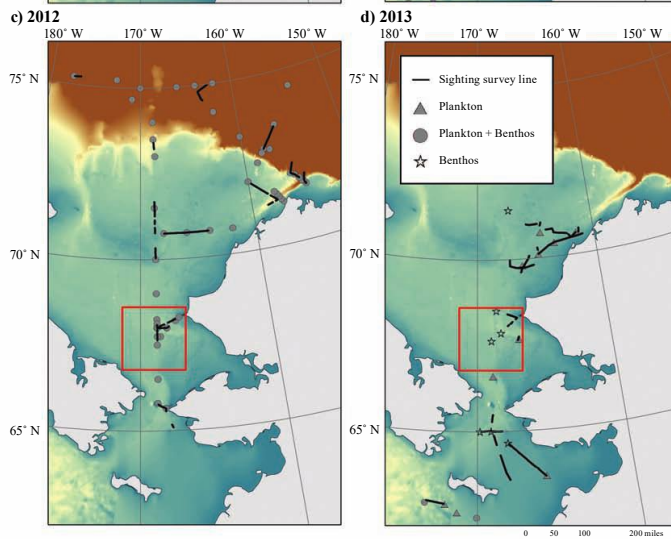
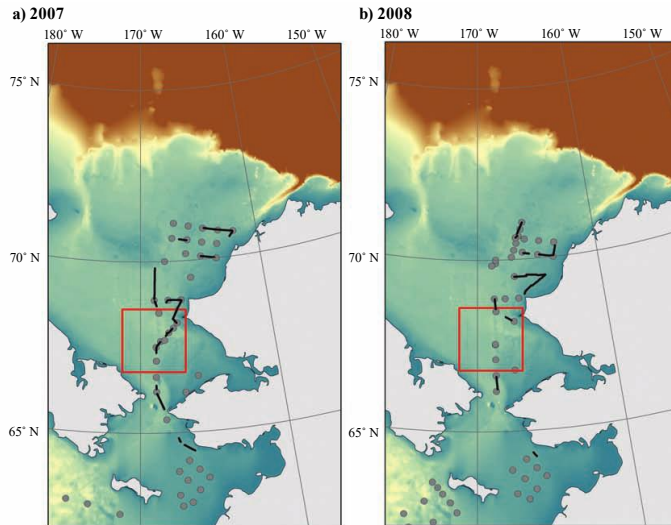
Ampeliscid energy density in the PAR (1970-2021)



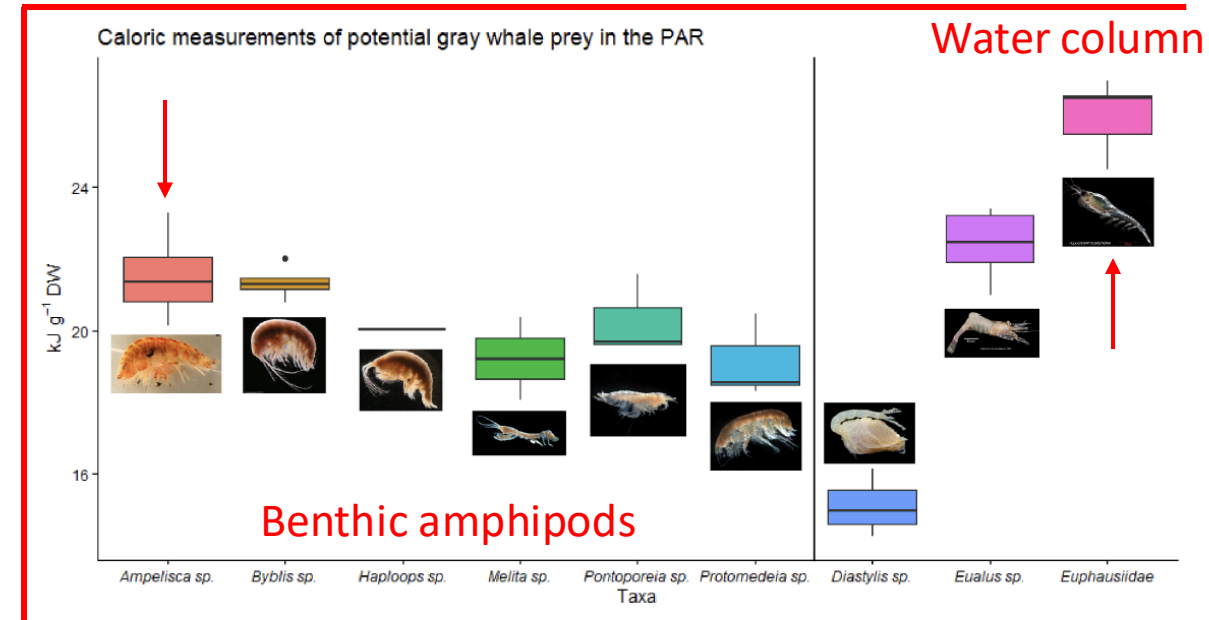
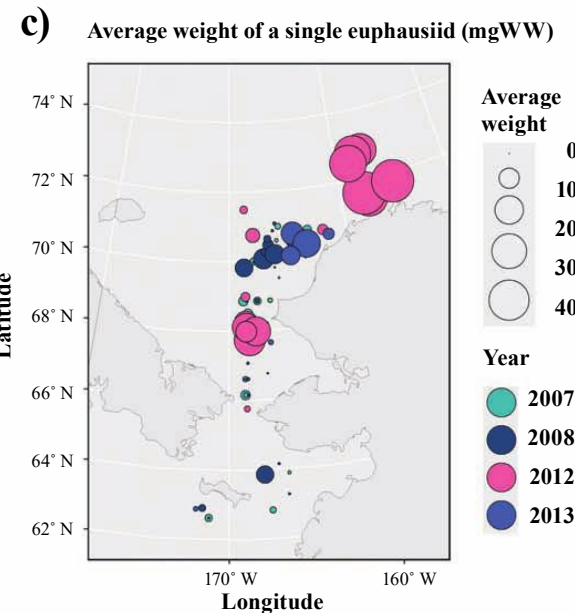
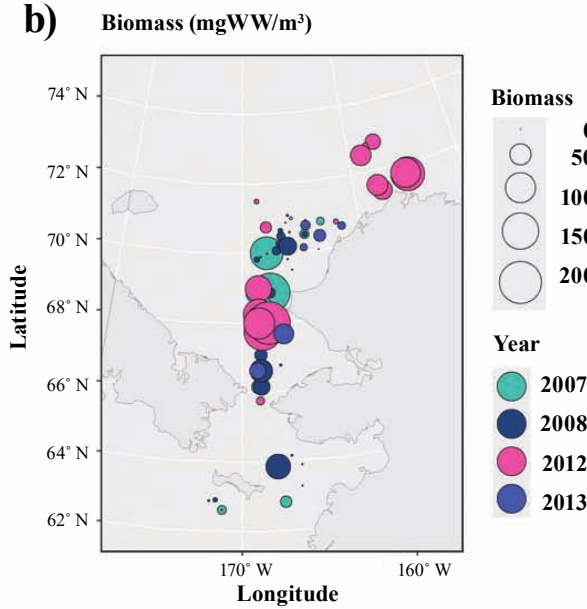
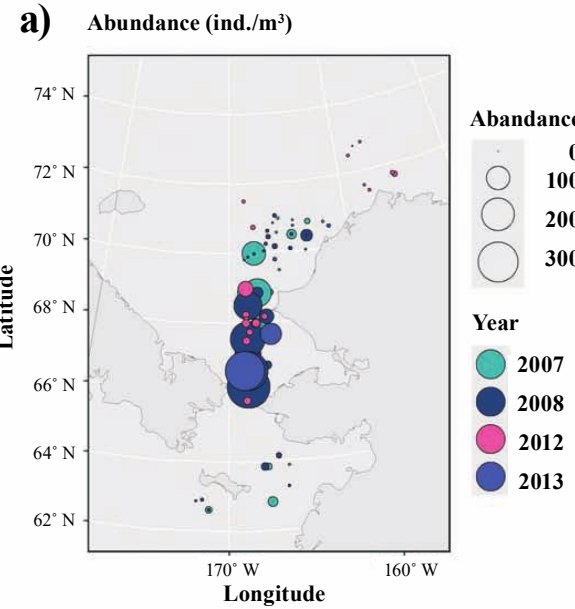
# Alternate water column zooplankton prey: euphausiids



Euphausiids



[Iwahara et al. 2025]



[B. Marx poster]

# Pacific Arctic Ecosystem Headlines

## SEA ICE

- Record Seasonal Retreats in 2007, **2012** & 2016, 2020
- Sea Ice Loss: by area and volume; longer ice-free period
- **‘Surprise’ winter sea ice loss near Bering Strait in 2017, 2018 & 2019**

## HEAT STORMS ADVECTION

- **Very Warm Seas:** SST, Bering Strait Inflow bringing **heat** & **freshwater** to Chukchi Sea
- **Increasing Storms** in High Arctic: deep mixing & upwelling
- Advection: **50% increase in transport of nutrients and plankton**

## PRIMARY PRODUCTION

### • **Primary Production**

- Under-ice phytoplankton blooms reported in some areas; increasing productivity with open water
- Harmful Algal Blooms (HABS) more prevalent in warming seas (*Lefebvre talk*)

## BENTHIC BIOMASS

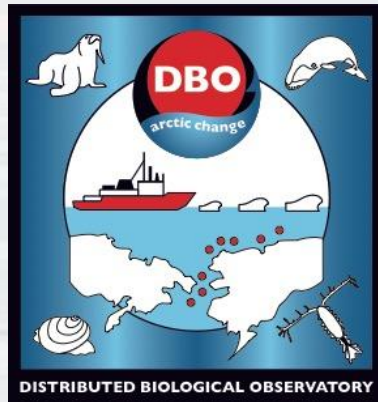
### • **Benthic Biomass**

- Significant decline in benthic amphipod biomass in historic prey bed for gray whales in the Chirikov Basin
- Spatial contraction of amphipod bed in Chirikov Basin
- Likely gray whale switch to plankton consumption when benthic crustaceans not available

**These changes have happened much faster than predicted**

# Thank you for your attention.

Thank you to all collaborators, field and laboratory technicians over the years for the time series efforts. We thank the Captain and crews of the CCGS Sir Wilfrid Laurier, USCGC Healy, RV Sikuliaq, and RV Norseman II for excellent support for the DBO program. Financial support for the science provided by the US NSF, NOAA, NASA, ONR, USFWS and ongoing international science partners in Department of Fisheries and Oceans Canada, the University of Victoria, and other international partners in the Pacific Arctic Group.



<https://dbo.cbl.umces.edu/>

Arctic Data Center(ADC)

<https://arcticdata.io/catalog/portals/DBO/Data>

National Centers for Environmental Information (NCEI)

<https://www.ncdc.noaa.gov/data-access>



# Increased algal toxin exposure risks to marine mammals are a major consequence of ocean warming

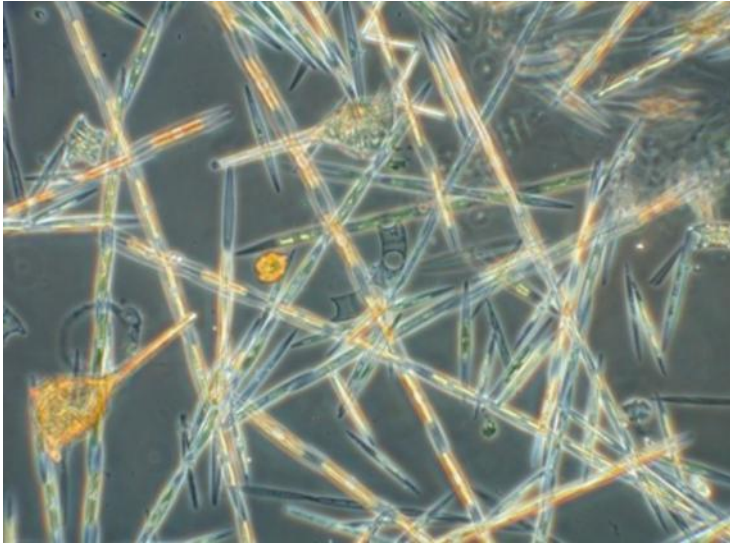
*Kathi Lefebvre*  
*Kathi.Lefebvre@noaa.gov*  
*NOAA/NWFSC, WARRN-West*



Photo by Kathi Lefebvre

# Harmful Algal Bloom (HAB) Toxins of Concern

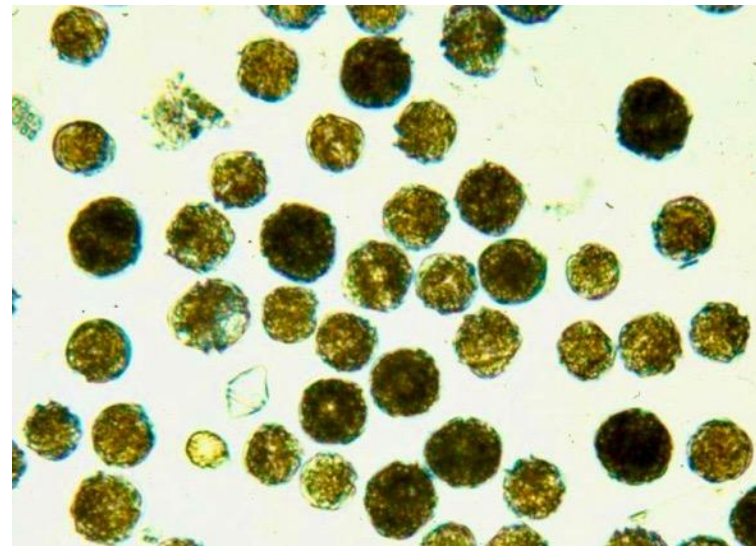
Image credit: Raphe Kudela Lab UCSC



Toxic diatoms (*Pseudo-nitzschia*)  
produce **DOMOIC ACID**

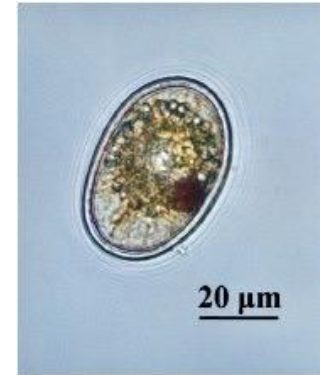
**Domoic Acid (DA)** = Excitotoxin  
responsible for **Amnesic Shellfish Poisoning (ASP)**  
Symptoms include; GI distress, confusion, seizures,  
memory loss, coma, death

Image credit: Don Anderson lab WHOI



Toxic dinoflagellates (*Alexandrium*)  
produce **SAXITOXIN**

**Saxitoxin (STX)** = Sodium channel blocker  
responsible for **Paralytic Shellfish Poisoning (PSP)**  
Symptoms include; tingling lips, paralysis,  
respiratory distress, coma, death



Cyst

# Wildlife Algal-toxins Research & Response Network

## WARRN-West



Provides surveillance for the presence of algal toxins in sick, stranded, dead & subsistence harvested marine mammals for the entire West Coast of North America  
***(Northern AK to Southern CA).***

### WARRN-West Team

*Northwest Fisheries Science Center*

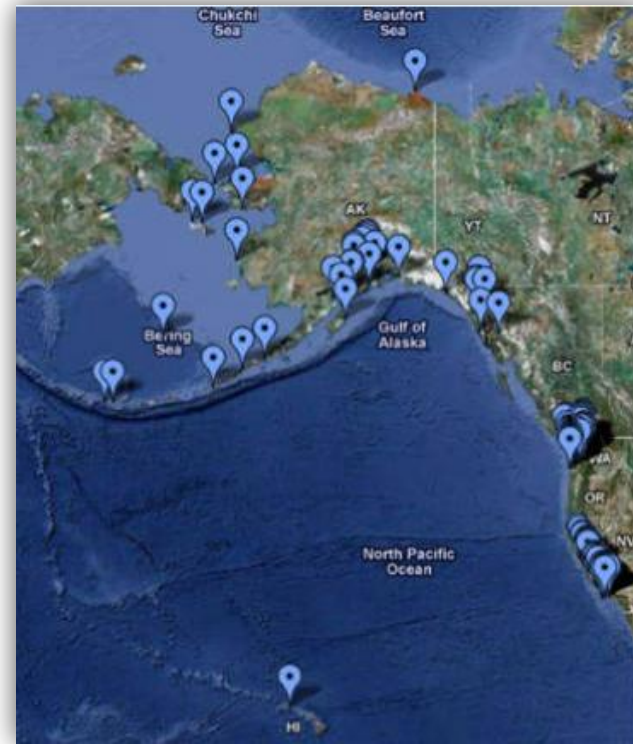
*Seattle, WA*

Kathi Lefebvre

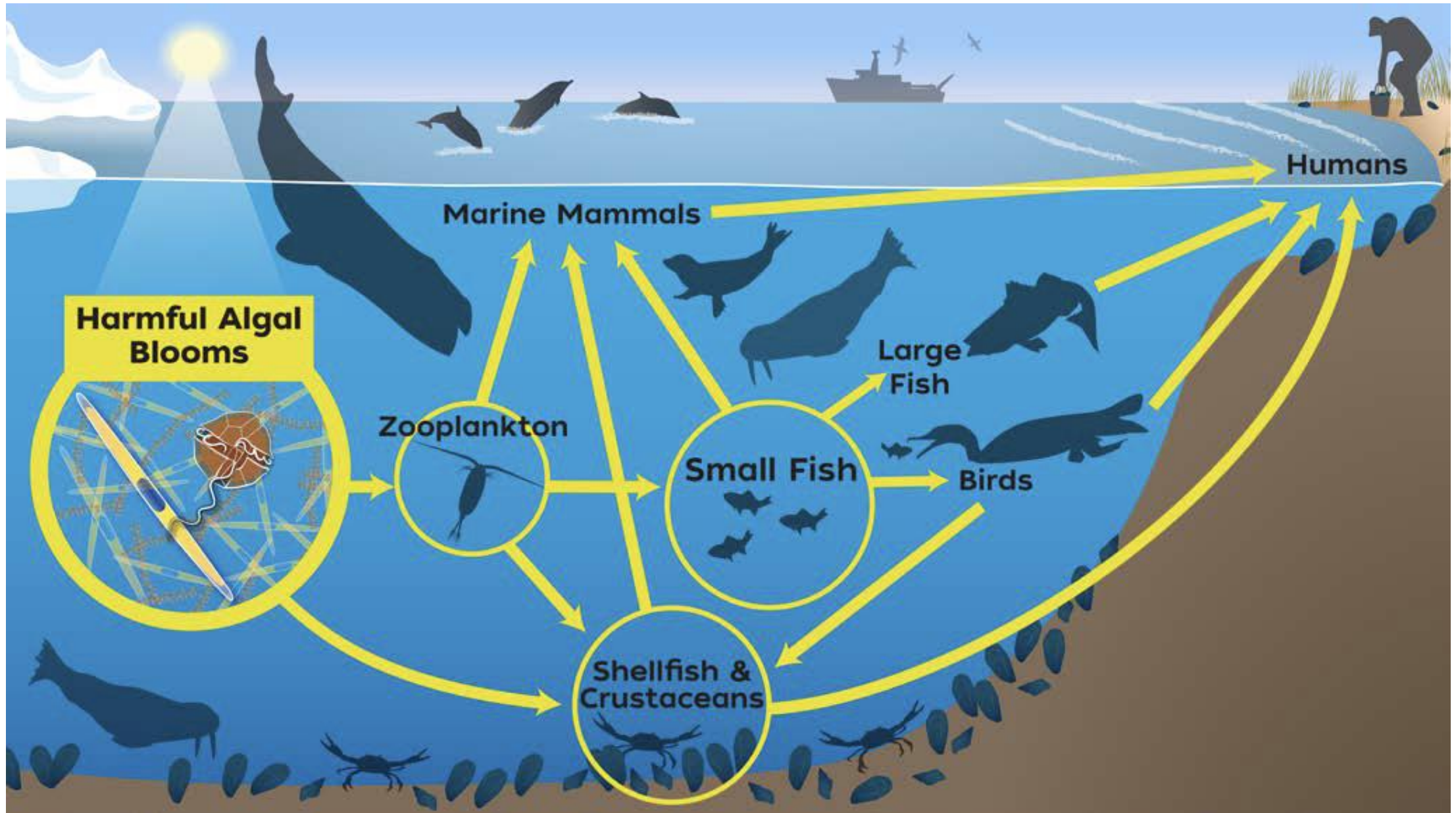
Emily Bowers

Patrick Charapata

*(left to right).*



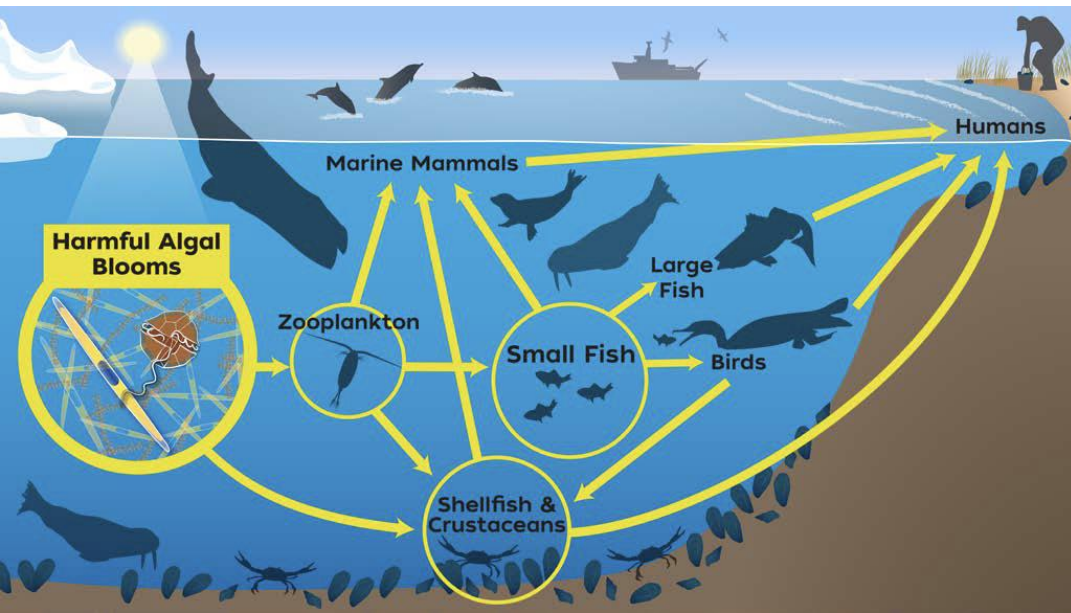
# Algal toxins are transferred through food webs



ECOHAB Team Sitka, AK  
May 2023



Algal toxins are present in Arctic & subarctic food webs!

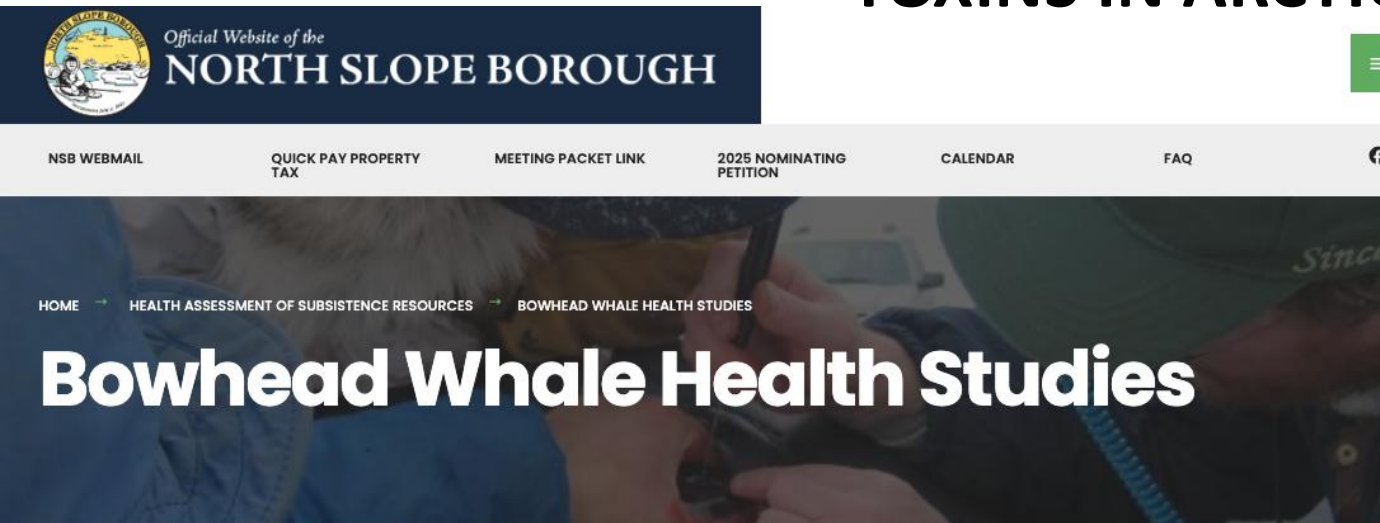


## WARRN West Marine Mammals Tested for DA & STX from Alaska (2004 to 2013)



Lefebvre, K.A., et al., Prevalence of algal toxins in Alaskan marine mammals foraging in a changing arctic and subarctic environment. Harmful Algae, 2016. 55: p. 13-24.

# BOWHEAD WHALES AS BIOSAMPLERS FOR THE PRESENCE OF ALGAL TOXINS IN ARCTIC FOOD WEBS



RAPHAELA STIMMELMAYR



Fecal Sample Collection

## Bowhead Whale Health Studies



Successful whaling crew. Photo credit: NSB-DWM

## Bowhead Harvest Sampling

### WILDLIFE MANAGEMENT

← Previous menu item

### HEALTH ASSESSMENT OF SUBSISTENCE RESOURCES

Bowhead Whale Health Studies

Bowhead Whale Contaminant & Nutrient Study

Fish Health Studies

Seal & Walrus Health Studies

Migratory Bird Health Assessments

- Collected fecal samples from 205 whales during Fall harvests over 19 years (2004-2022: 3 to 19 whales per year)
- Quantified Algal Toxins (domoic acid-Amnesic Shellfish Poisoning & saxitoxin- Paralytic Shellfish Poisoning)
- Toxin **concentration & prevalence** linked to climate conditions



Article

# Bowhead whale faeces link increasing algal toxins in the Arctic to ocean warming

<https://doi.org/10.1038/s41586-025-09230-5>  
Received: 12 December 2024  
Accepted: 3 June 2025  
Published online: 09 July 2025  
Open access

Kathi A. Lefebvre<sup>1✉</sup>, Patrick Charapata<sup>2</sup>, Raphaela Stimmelmayer<sup>3</sup>, Peigen Lin<sup>4</sup>, Robert S. Pickart<sup>5</sup>, Katherine A. Hubbard<sup>6</sup>, Brian D. Bill<sup>1</sup>, Gay Sheffield<sup>7</sup>, Emily K. Bowers<sup>1</sup>, Donald M. Anderson<sup>8</sup>, Evangeline Fachon<sup>5,9</sup> & Rick Thoman<sup>10</sup>

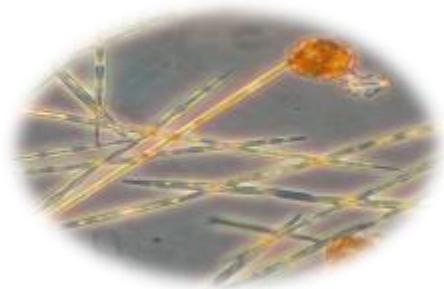
Over the last two decades, ocean warming and rapid loss of sea ice have dramatically changed the Pacific Arctic marine environment<sup>1–3</sup>. These changes are predicted to



**Bowhead**

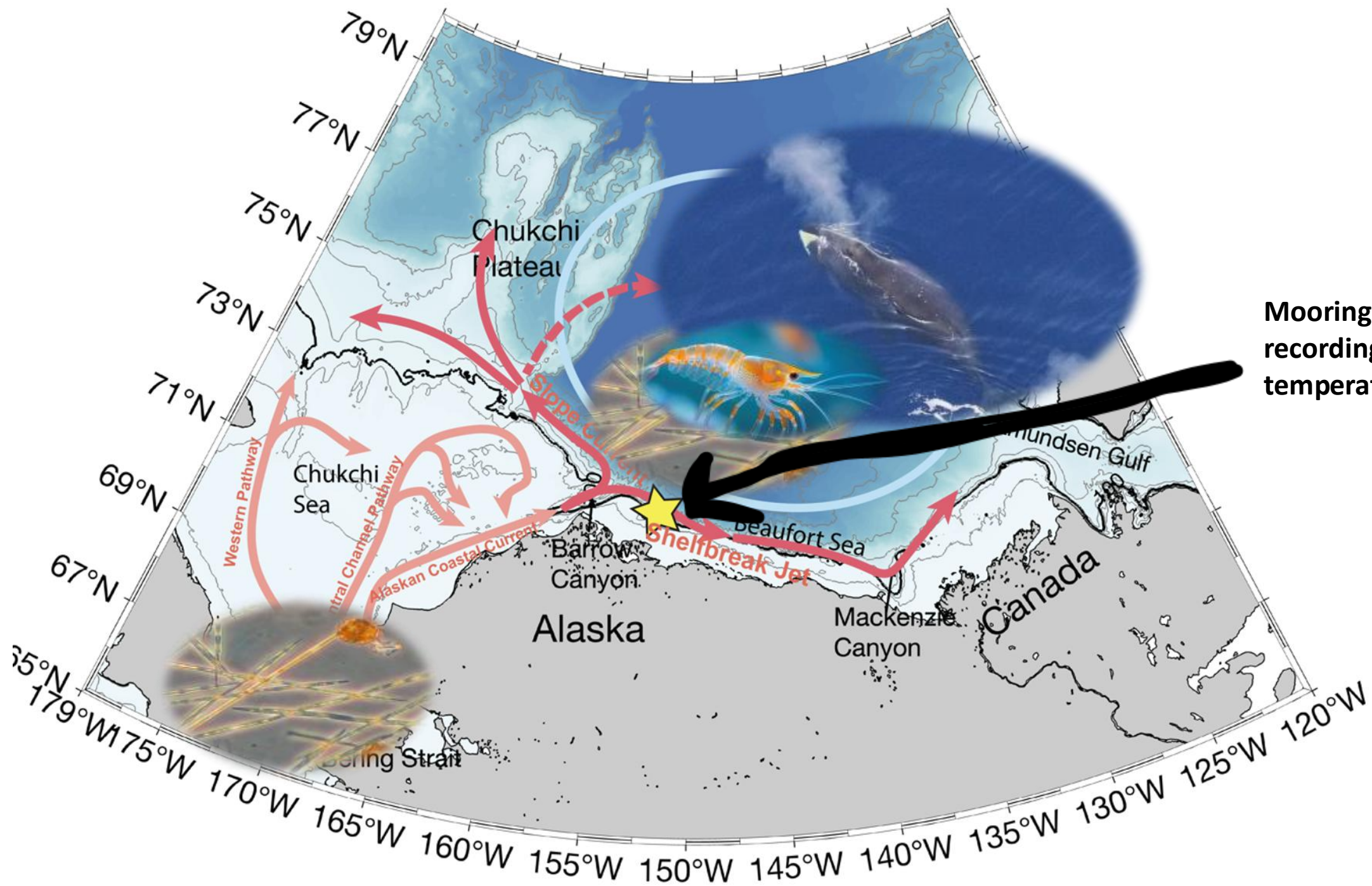


**Krill**



**Toxic Algae**

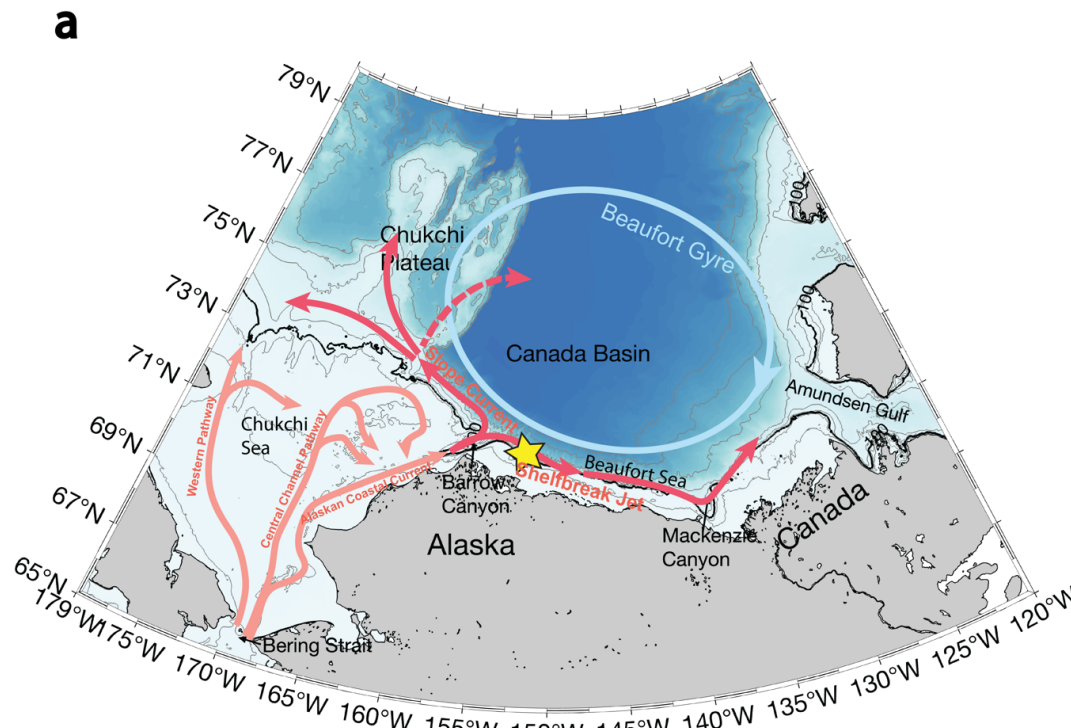
Domoic acid & Saxitoxin



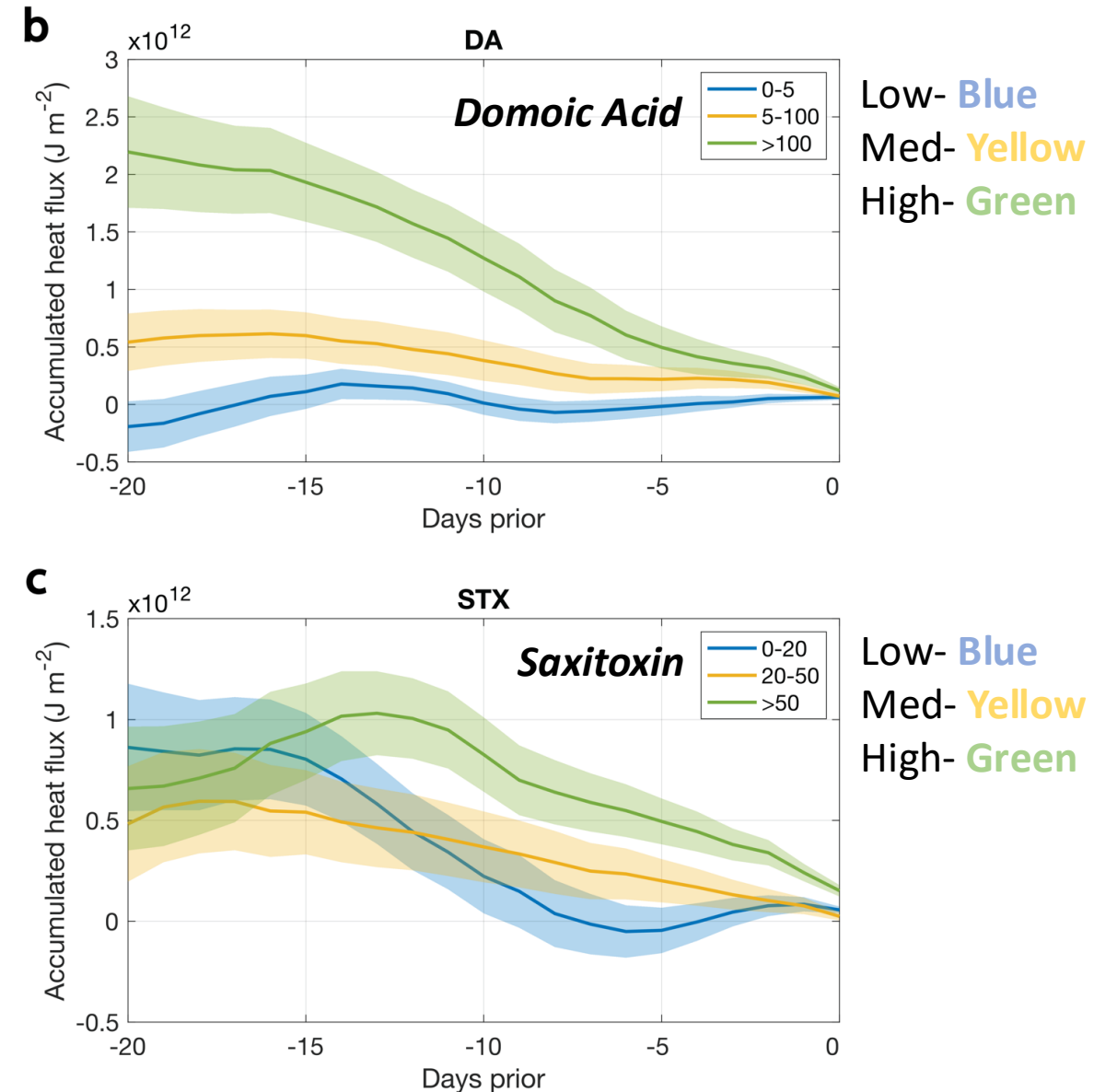
Mooring- long term recording of Ocean temperatures.

# Accumulated heat flux & algal toxin concentration

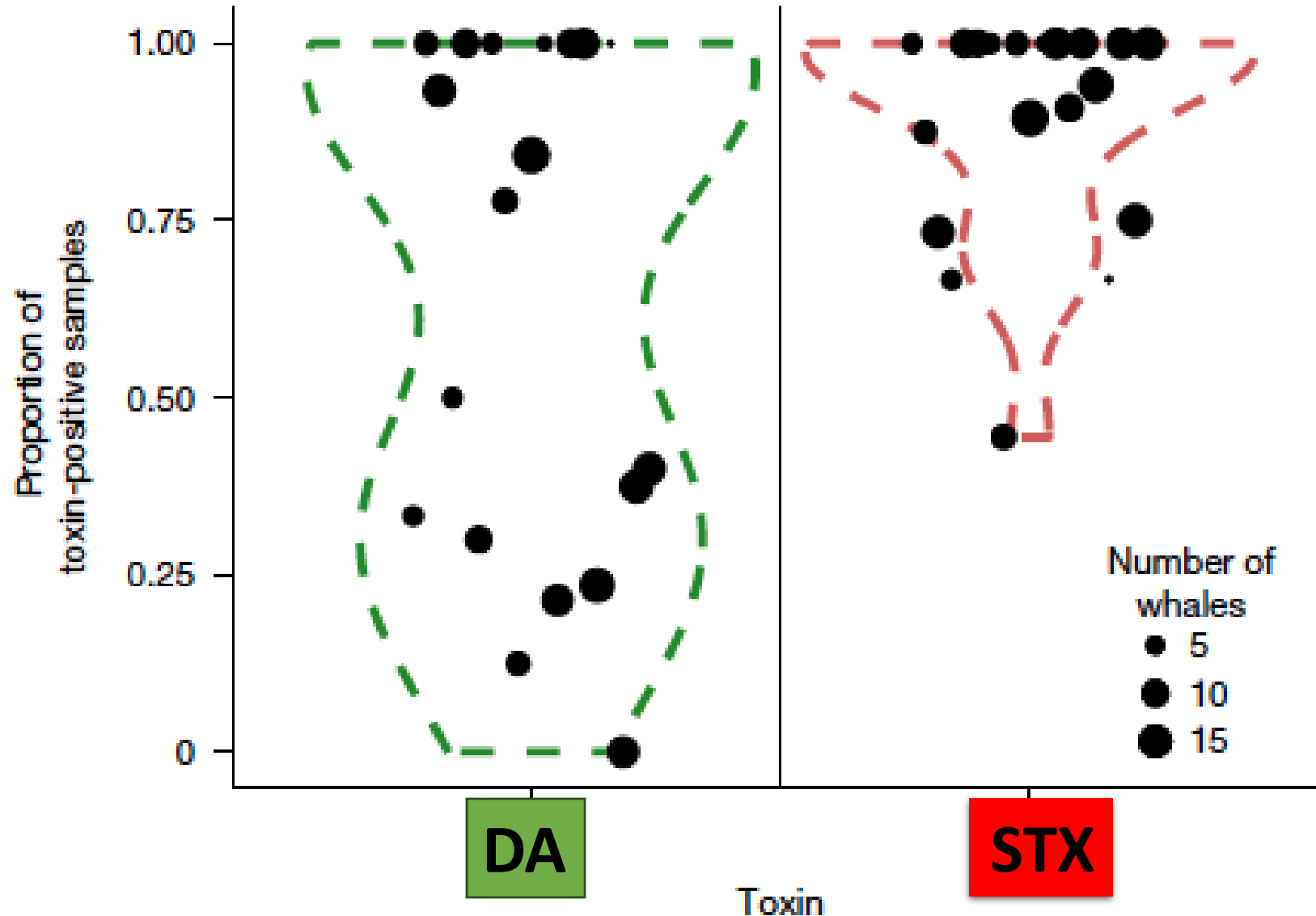
Three concentration groups;  
*low, medium, high*



**Warmer water linked to higher toxin concentrations for both toxins!**



# Distribution of yearly toxin **prevalence** for DA & STX

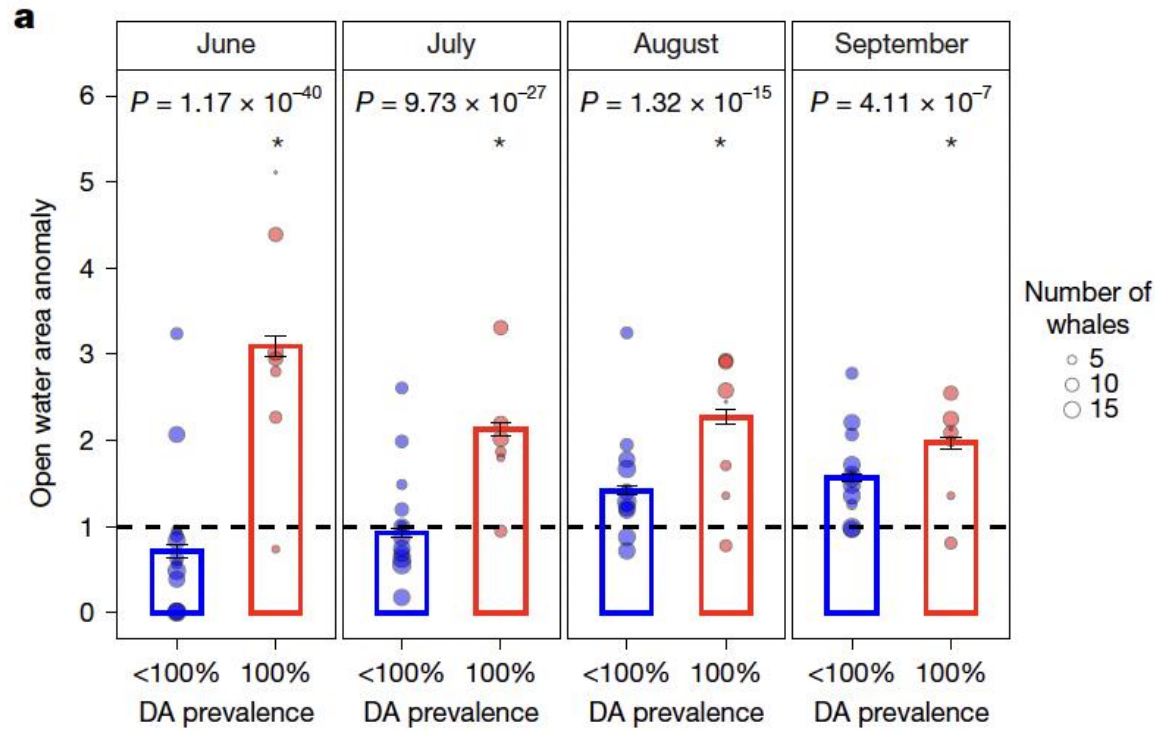


Prevalence:

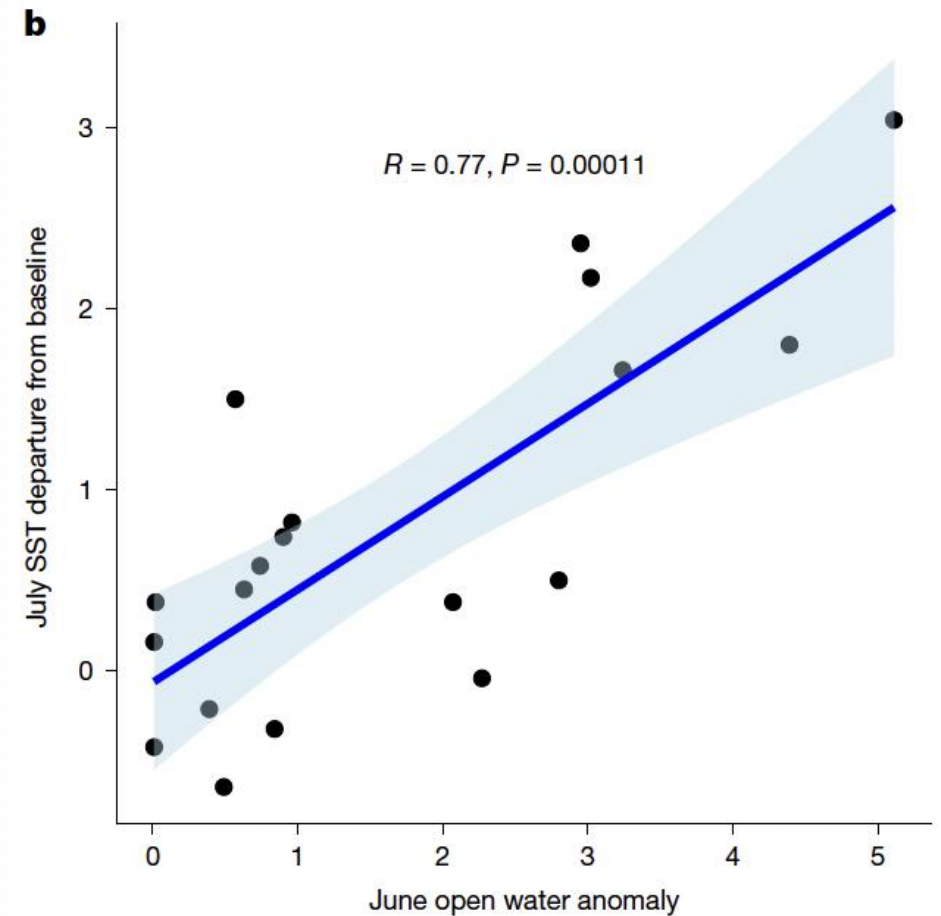
**DA** 0% - 100%

**STX** 45 % - 100%

# Open water area & algal toxin prevalence



Significantly more open water area in years with 100% algal toxin prevalence (red bars)



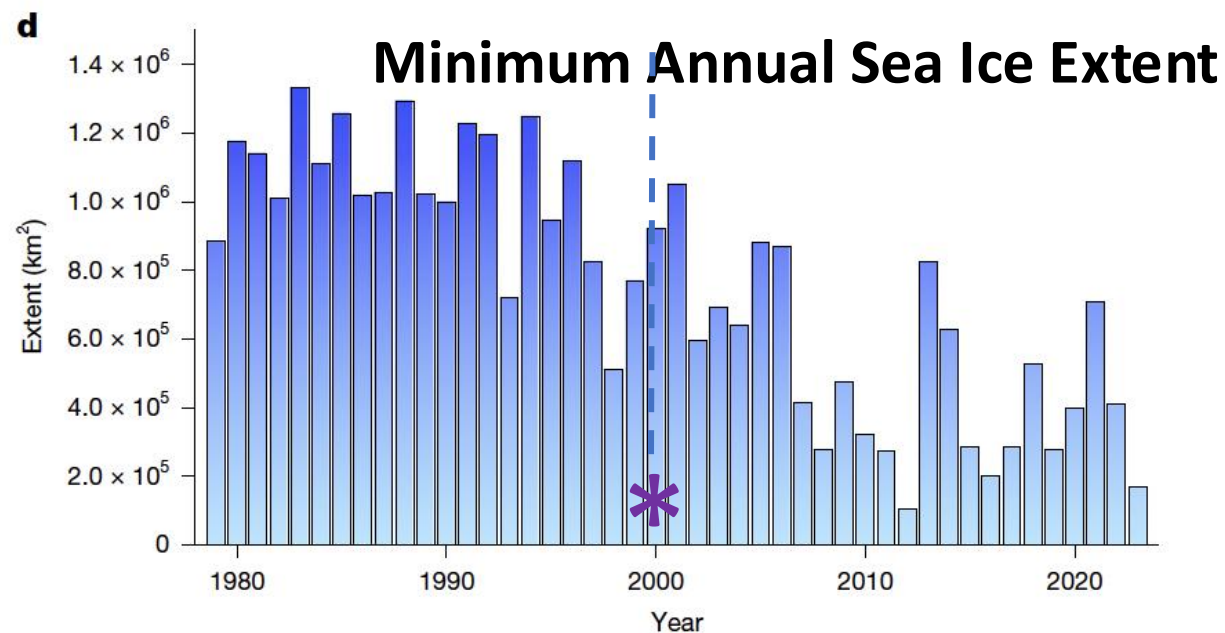
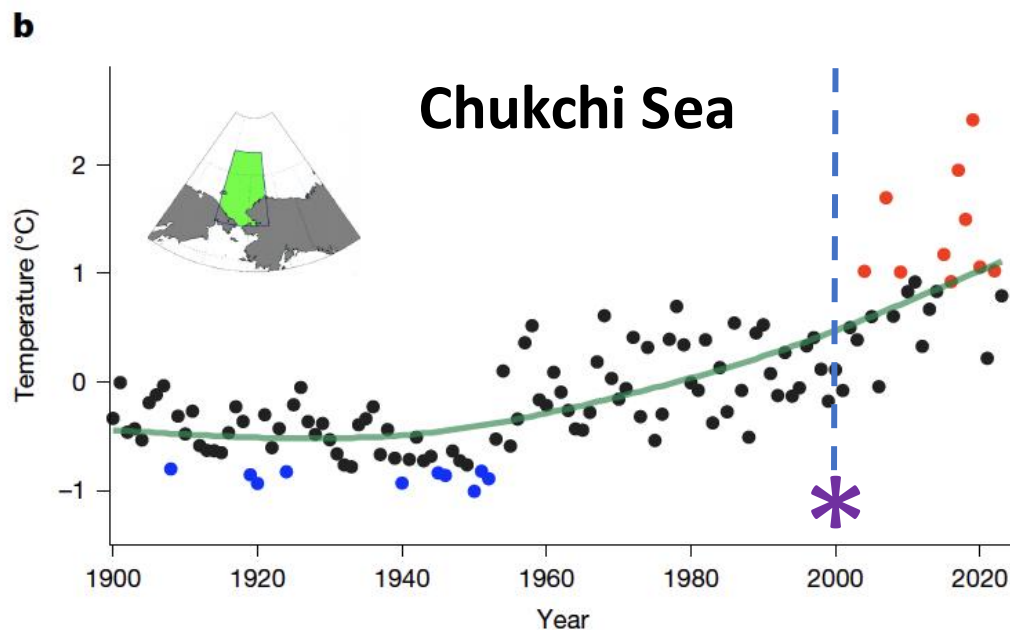
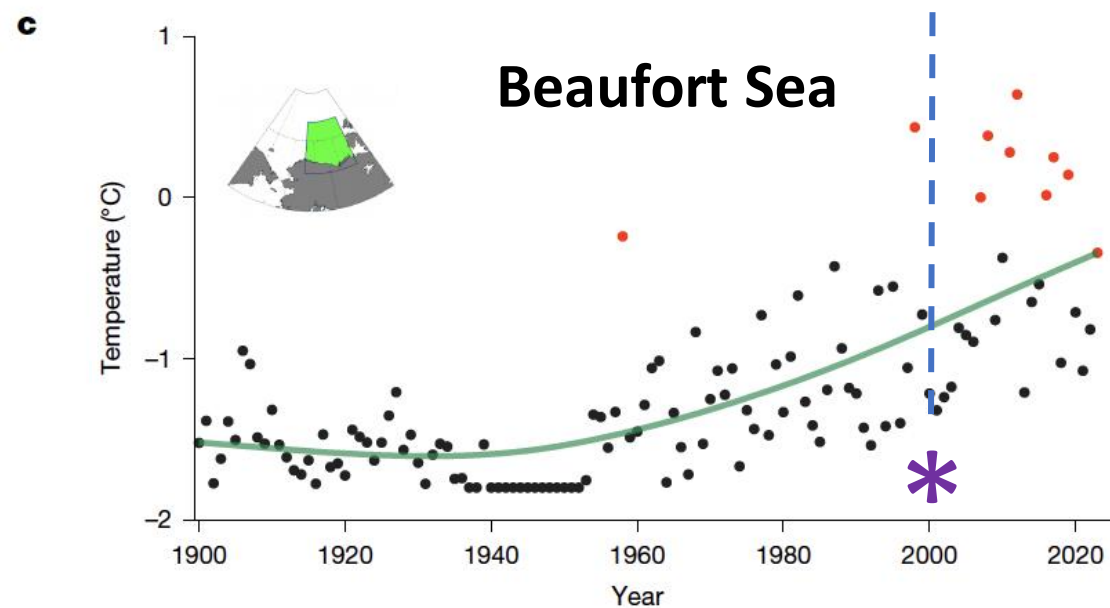
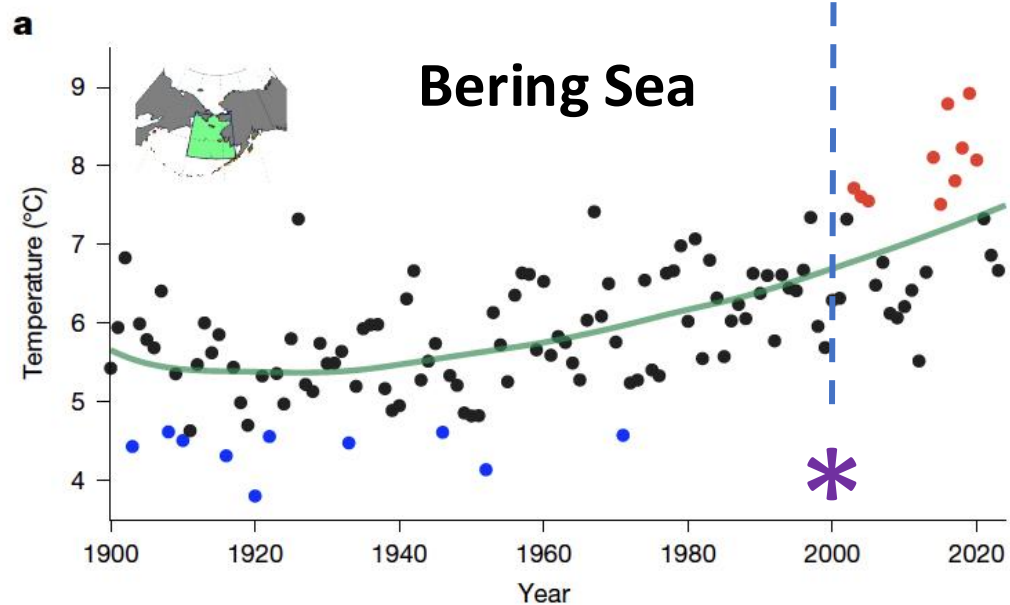
More open water area in June linked to higher SST in July

# Warmer conditions = more toxins in food web

- Higher heat flux = higher toxin concentrations
- More open water (loss of sea ice) = higher toxin prevalence



# Increasing risks with accelerated warming of Arctic!





**Toxicologist**

Kathi Lefebvre  
NOAA/WARRN-West



**Physiologist**

Patrick Charapata  
Georgia Aquarium



**Veterinarian**

Raphaella Stimmelmayer  
North Slope Borough



**Physical Modeler**

Peigen Lin  
Shanghai University



**Physical Oceanographer**

Bob Pickart  
WHOI



**Conservation Biologist**

Kate Hubbard  
Fish & Wildlife Conservation

*Lefebvre, K.A., et al., Bowhead whale faeces link increasing algal toxins in the Arctic to ocean warming. Nature, 2025.*



**Phycologist**

Brian Bill  
NOAA/WARRN-West



**Arctic Wildlife Biologist**

Gay Sheffield  
Sea Grant/UAF



**Toxin Chemist**

Emily Bowers  
NOAA/WARRN-West



**Ecologist/Oceanographer**

Don Anderson  
WHOI



**Ecologist/Oceanographer**

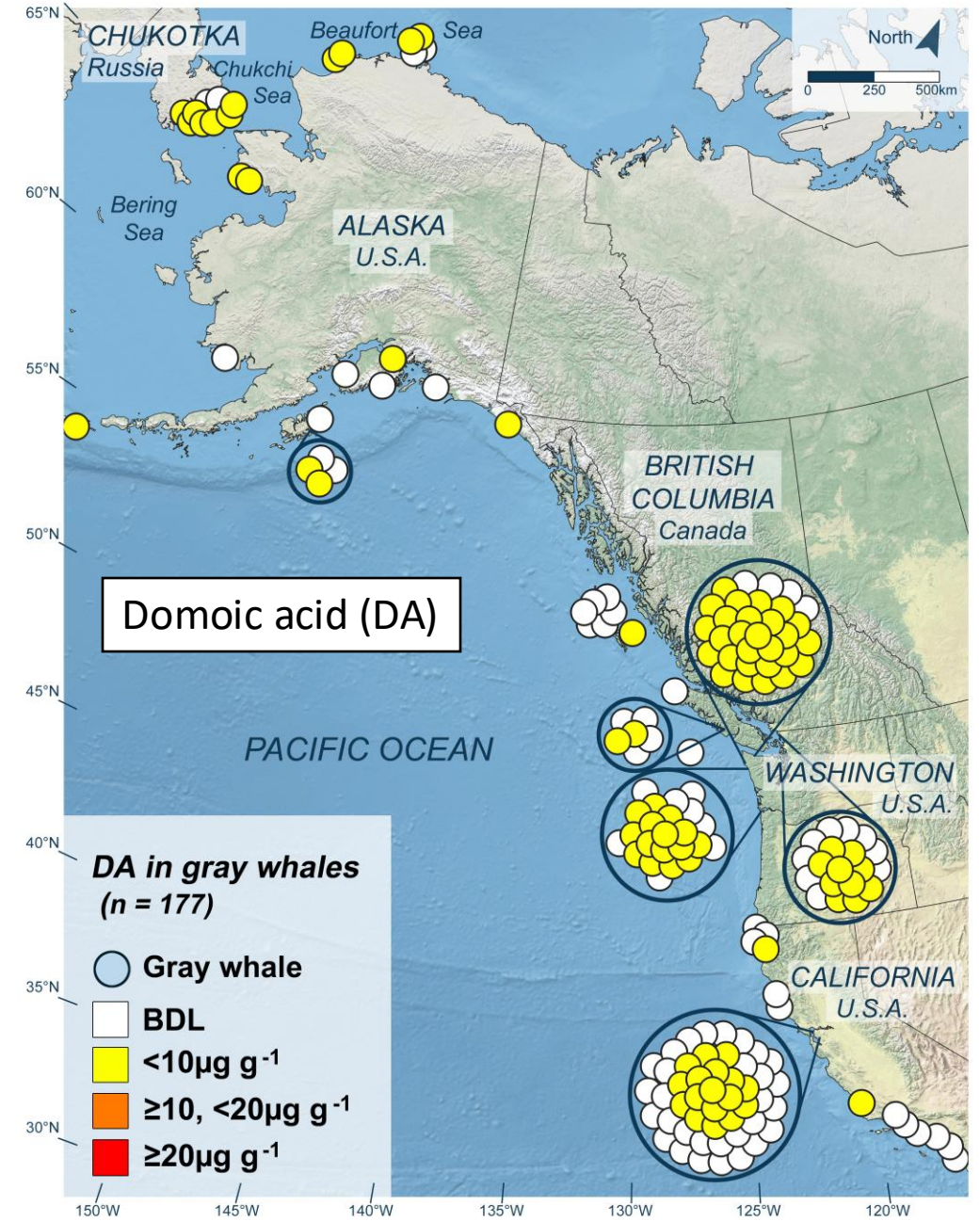
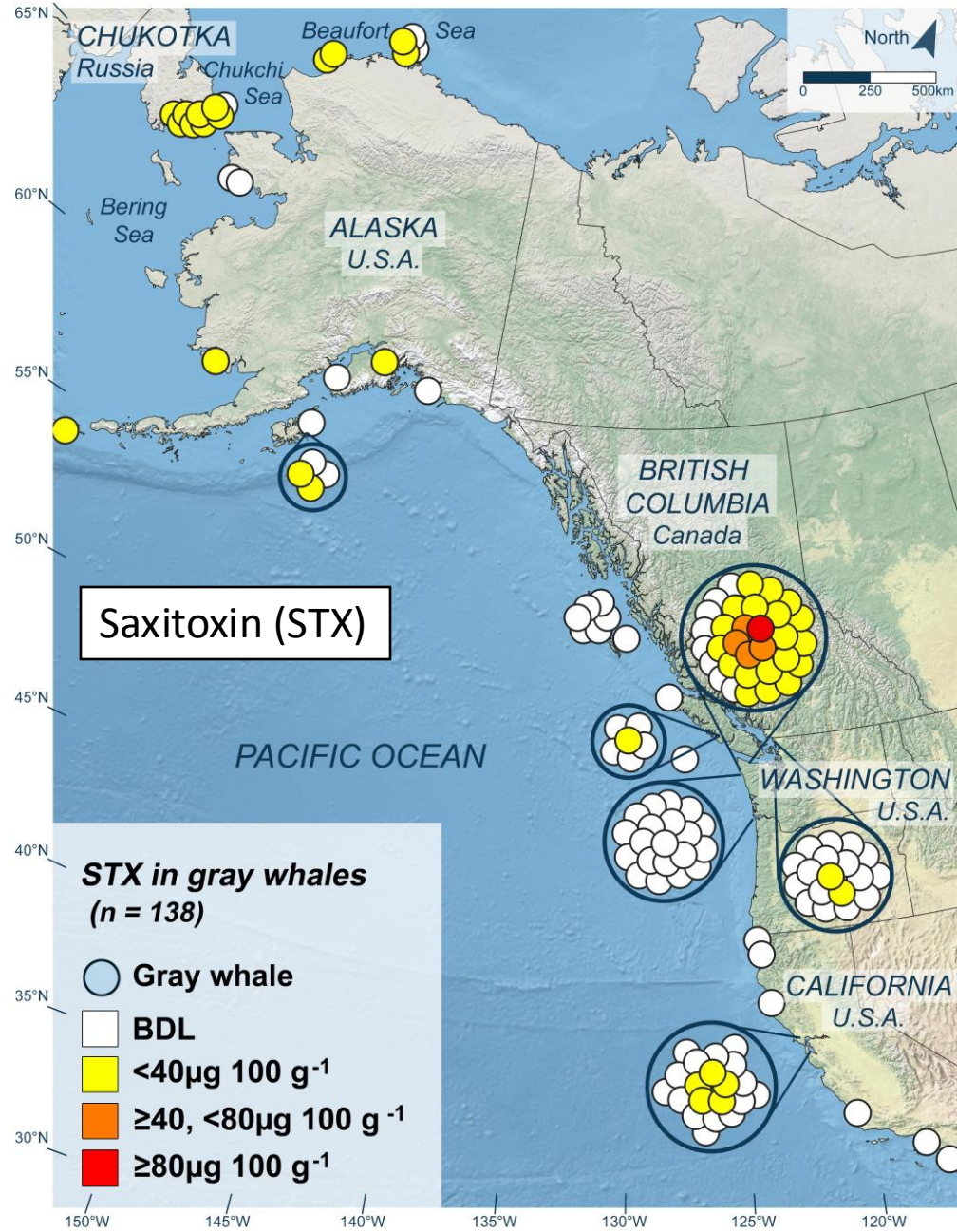
Evie Fachon  
WHOI



**Climatologist**

Rick Thoman  
UAF

# WARRN West Gray Whales Analyzed



# Saxitoxin Linked to Deaths of Northern Fur Seals in the Southeast Bering Sea

Kathi A. Lefebvre<sup>1</sup>  | Chelsea M. Campbell<sup>2,3</sup> | Lauren M. Divine<sup>2</sup> | Paul Melovidov<sup>2</sup> | Hanna Hellen<sup>2</sup> | Kathy Burek Huntington<sup>4</sup> | Emily K. Bowers<sup>1,5</sup> | Natalie Rouse<sup>4</sup> | Evangeline Fachon<sup>6,7</sup>  | Thomas J. Farrugia<sup>8</sup> | Robert S. Pickart<sup>6</sup>  | Peigen Lin<sup>9</sup> | Lorely Lago<sup>6</sup> | Frank Bahr<sup>6</sup> | Emmanuelle Furst<sup>10</sup> | Colleen G. Duncan<sup>11</sup> | Patrick Charapata<sup>12</sup> | Donald M. Anderson<sup>6</sup> | Gulce Kurtay<sup>13,14</sup>

Marine Mammal Science



**Photo credit:** *Paul Melovidov, Aleut Community of St. Paul Island, Alaska*



ECOHAB Team Sitka, AK  
May 2023



NOAA National Centers for Coastal Ocean Science  
ECOHAB grant no. NA20NOS4780195 awarded to;  
Kathi Lefebvre (Northwest Fisheries Science Center, Seattle, WA)  
Don Anderson (Woods Hole Oceanographic Institution).

ECOHAB Kick off meeting  
Nome, AK April 2026



# Session 3 Discussion

## Ecosystem Changes Impacting Gray Whales

**Virtual**



Nate Mantua

**In-person**



Jackie Grebmeier



Kathi Lefebvre



Kate Stafford