Case Studies

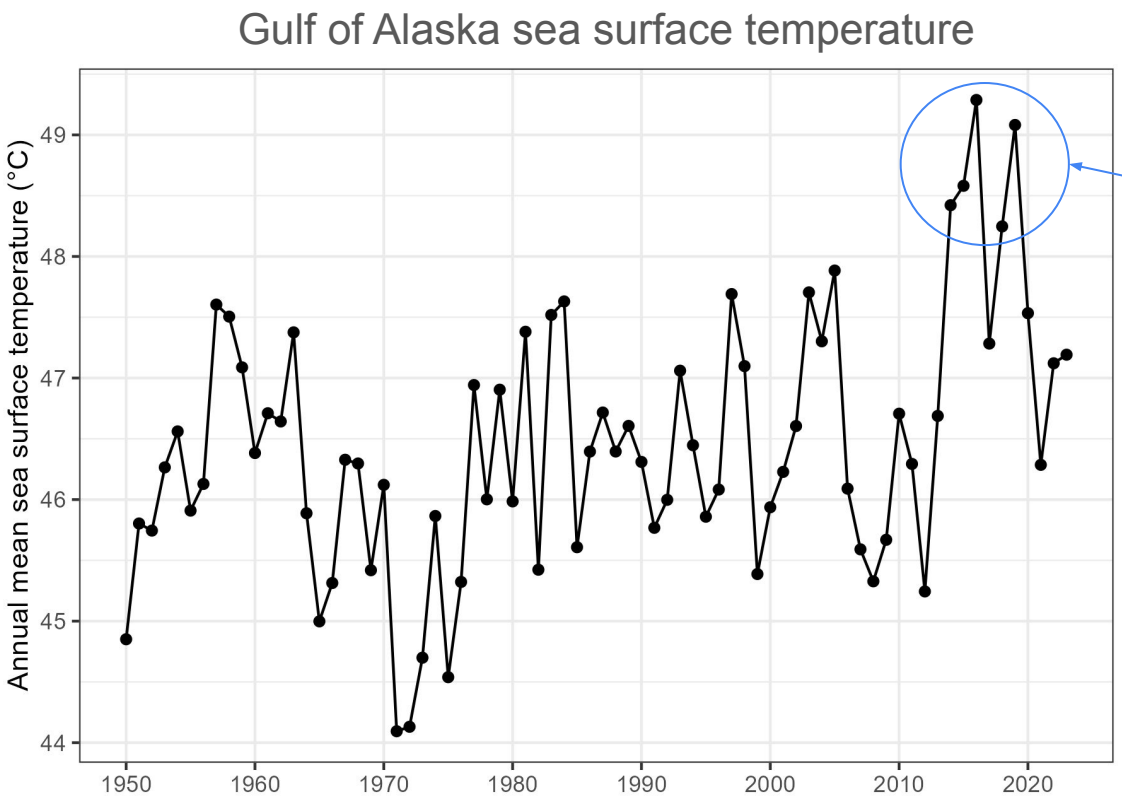
Mike Litzow, NMFS AFSC, Kodiak Lab Director
Erin Fedewa, NMFS AFSC, Kodiak Lab
Ebett Siddon, NMFS AFSC, Auke Bay Lab
Dana Hanselman, SSC; NMFS AFSC Auke Bay Lab Director

Gulf of Alaska Pacific cod

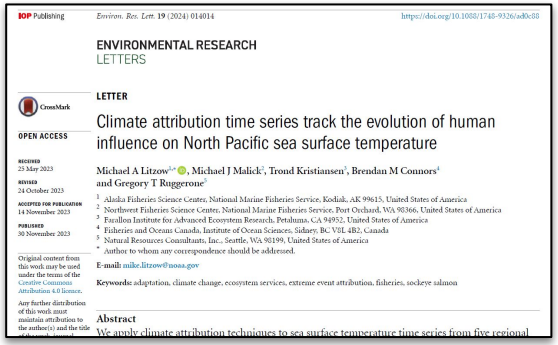
With contributions from
Steve Barbeaux, AFSC

What happened?

Unprecedented warming, 2014-2019



20-100 times more likely now than in the preindustrial climate



IOP Publishing Environ. Res. Lett. 19 (2024) 014014 https://doi.org/10.1088/1748-9326/ad0c88

ENVIRONMENTAL RESEARCH
LETTERS

LETTER

Climate attribution time series track the evolution of human influence on North Pacific sea surface temperature

Michael A Litzow, Michael J Malick, Trond Kristiansen, Brendan M Connors and Gregory T Ruggerone

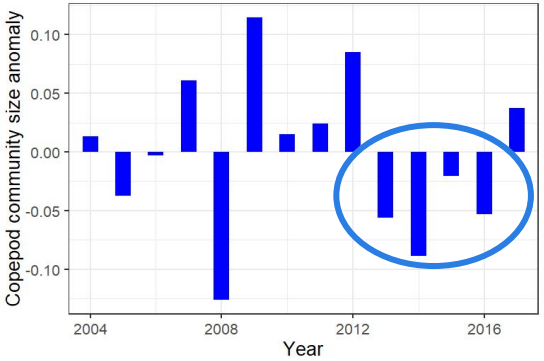
Abstract

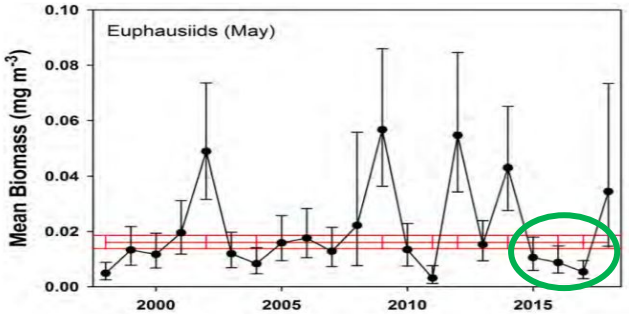
Ecological impacts of 2014-2016 warming

- Massive seabird die-offs and reproductive failure
- Increase in large whale strandings

Ecological impacts of warming

- Fewer large lipid-rich copepods
- Low euphausiid abundance
- Low forage fish abundance
- Lower forage fish quality





Frontiers in Marine Science 2020

Marine Heatwave Stress Test of Ecosystem-Based Fisheries Management in the Gulf of Alaska Pacific Cod Fishery

Steven J. Barbeaux, Kirstin Holsman and Stephani Zador*

Alaska Fisheries Science Center, National Oceanic and Atmospheric Administration (NOAA), Seattle, WA, United States

In 2014–2016 an unprecedented warming event in the North Pacific Ocean triggered changes in ecosystem of the Gulf of Alaska (GOA) impacting fisheries management. The marine heatwave was noteworthy in its geographical extent, depth range, and persistence, with evidence of shifts in species distribution and reduced productivity. In 2017 a groundfish survey indicated that GOA Pacific cod (*Gadus macrocephalus*) had experienced a 71% decline in abundance from the previous 2015 survey. The

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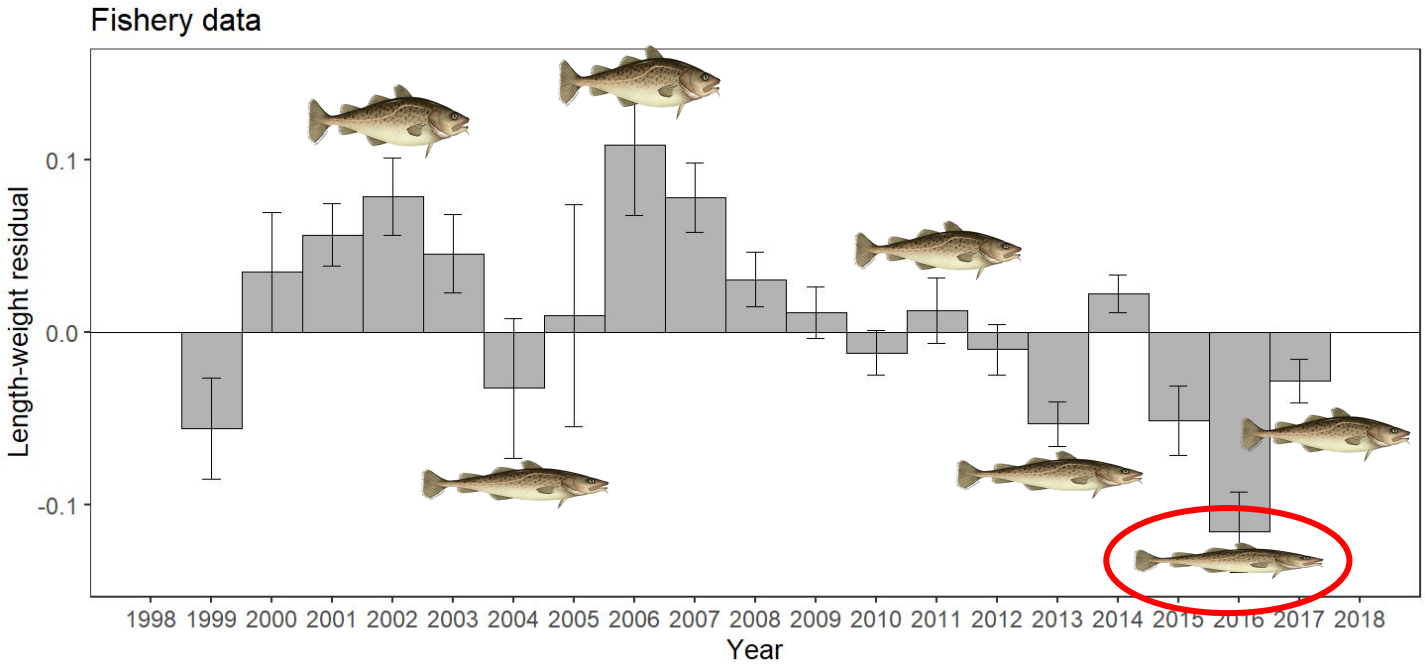
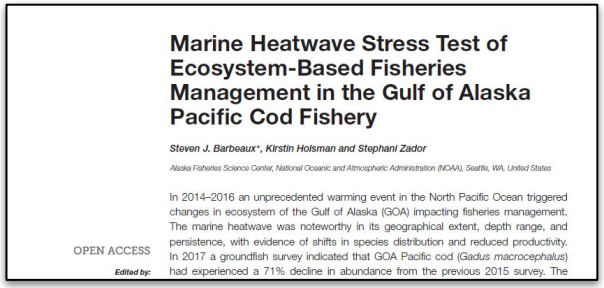


Poor condition and increased natural mortality for juveniles and adults

Frontiers in Marine Science 2020



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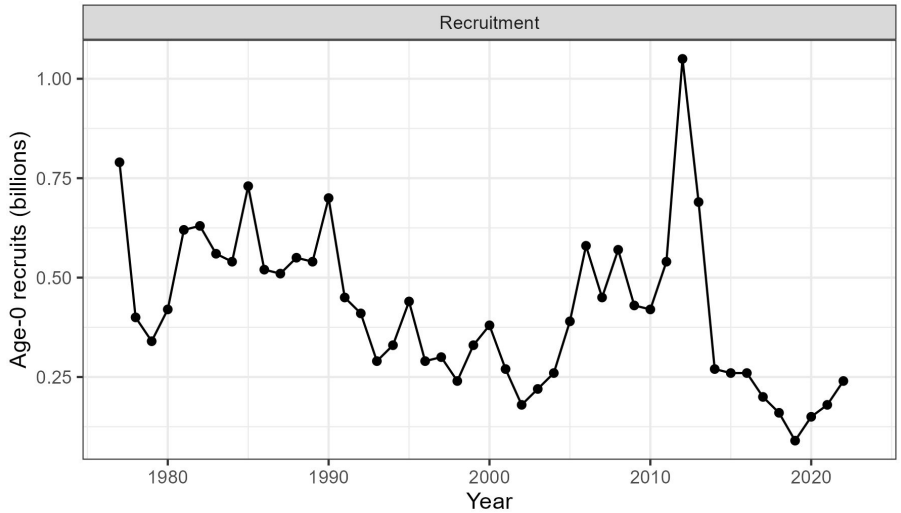
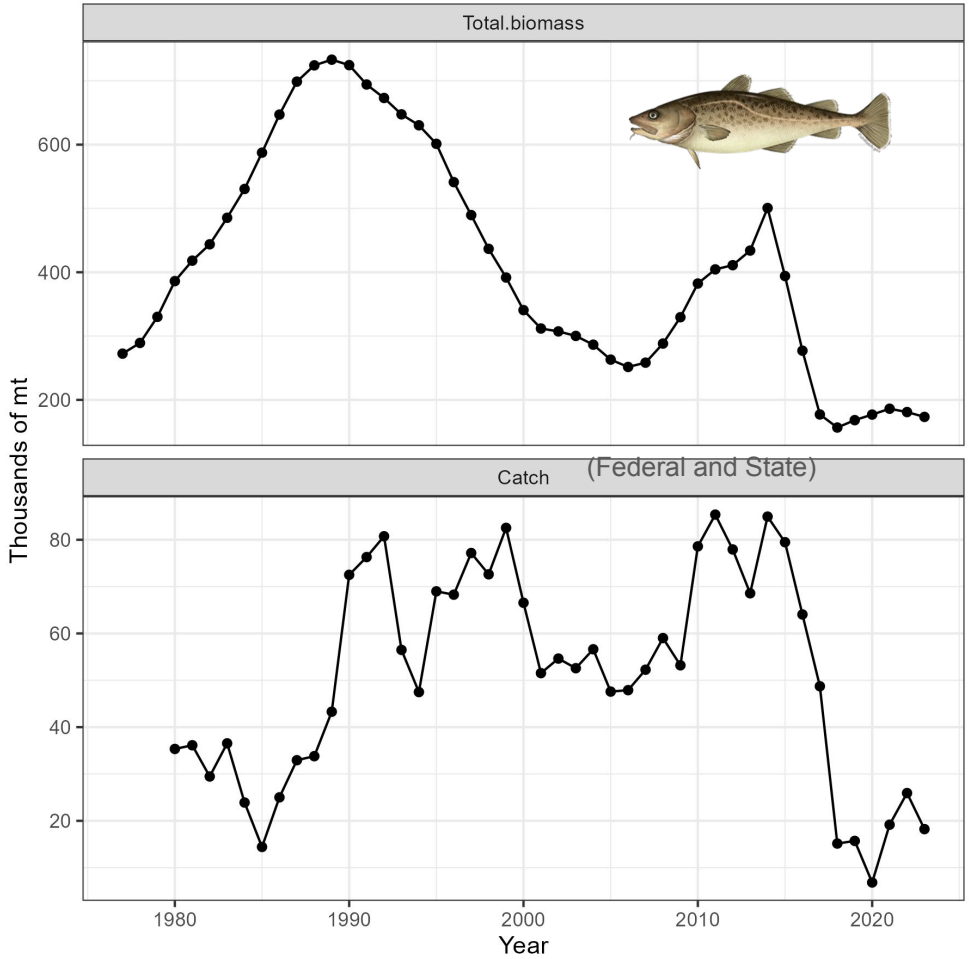
- Low egg survival
- Low recruitment
- High metabolic needs
- Poor forage
- High mortality
- Abrupt collapse, little recovery

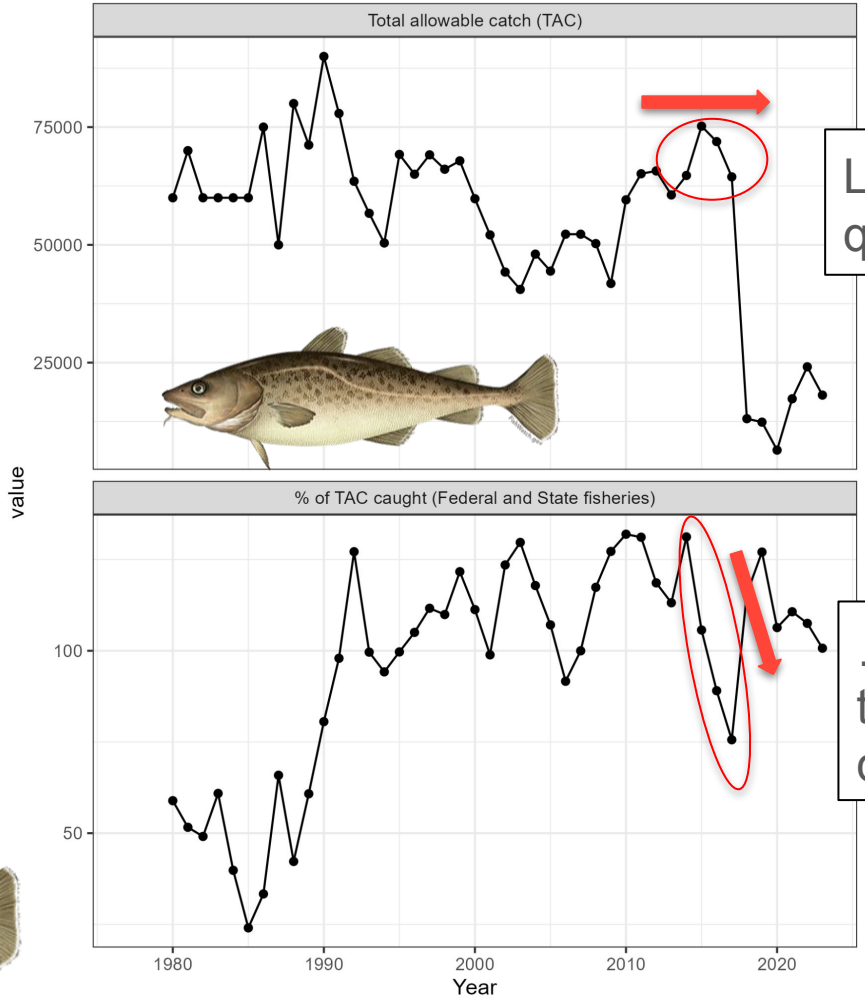




Source: 2023 SAFE, Tables 2.2, 2.16, 2.17

What information was available?
What was the response?

Fishery performance was a leading indicator of stock collapse.

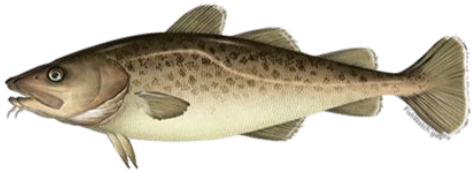


Little change in quotas…

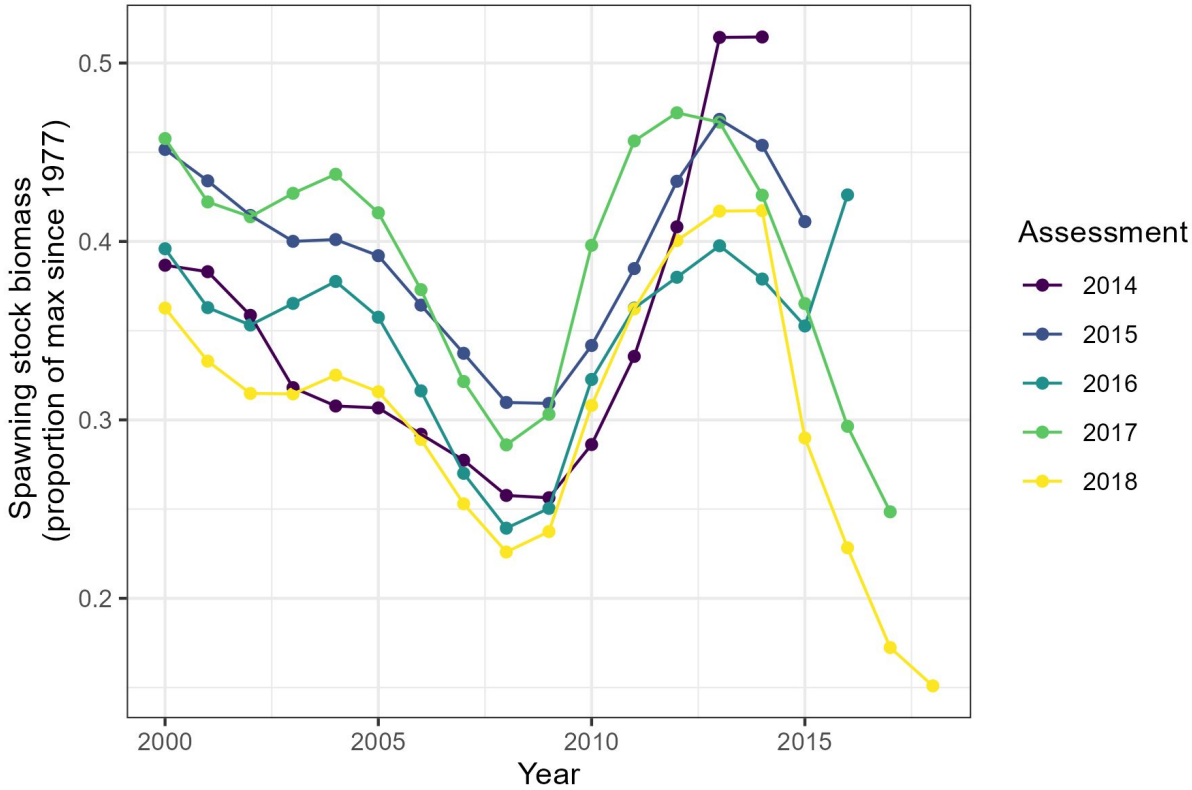
…even as ability to catch the quota plummets.

Not enough information was available at the time!

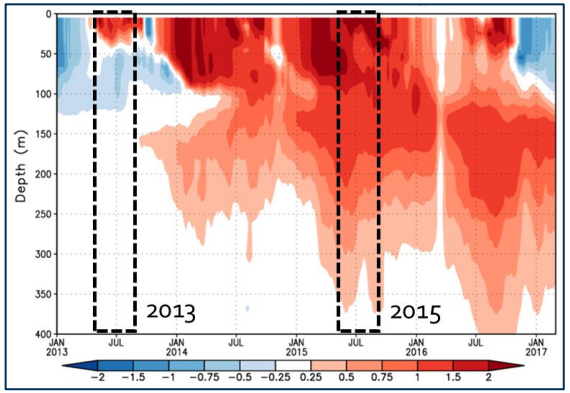
- Bottom trawl survey only every other year
- Bottom trawl survey has high observation error for Pacific cod (lots of noise in the data)
- Even though the collapse started in 2015, it wasn't detected until the 2017 assessment

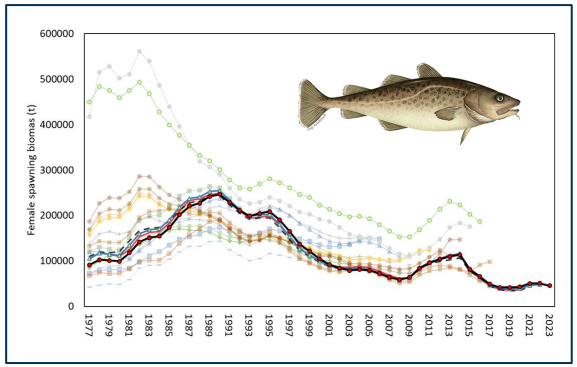


Spawning stock biomass estimates, 2014 - 2018 assessments



2017 Gulf of Alaska Pacific cod





Stock assessment

Increased natural mortality parameter during warm years to reflect reduced prey availability and increased mortality

Scientific & Statistical Committee

"The SSC accepts this adjustment to natural mortality to achieve a better model fit because of the **strong rationale presented by the author and the ecosystem group** in support of higher mortalities for the period 2015/2016."

Council

Quota was reduced by 80% for 2018

"There was a reason. People understood." - Council member

Lessons / questions

- Human-caused impacts on our fisheries are here now
- Detecting sudden population change took a long time
- Old ecological rules (“warm is good for GOA cod”) no longer apply
- Standard assumptions (constant natural mortality) may no longer apply
- Should we pay more attention to poor fishery performance?

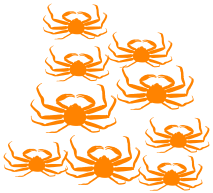
Bering Sea Snow Crab

Erin Fedewa, NOAA AFSC

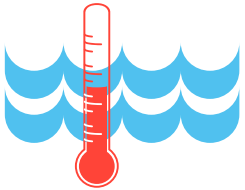
Contributions from: Cody Szuwalski, Mike Litzow, Ben Daly, Jamie Goen, Louise Copeman, and the AFSC Shellfish Assessment Program

What happened?

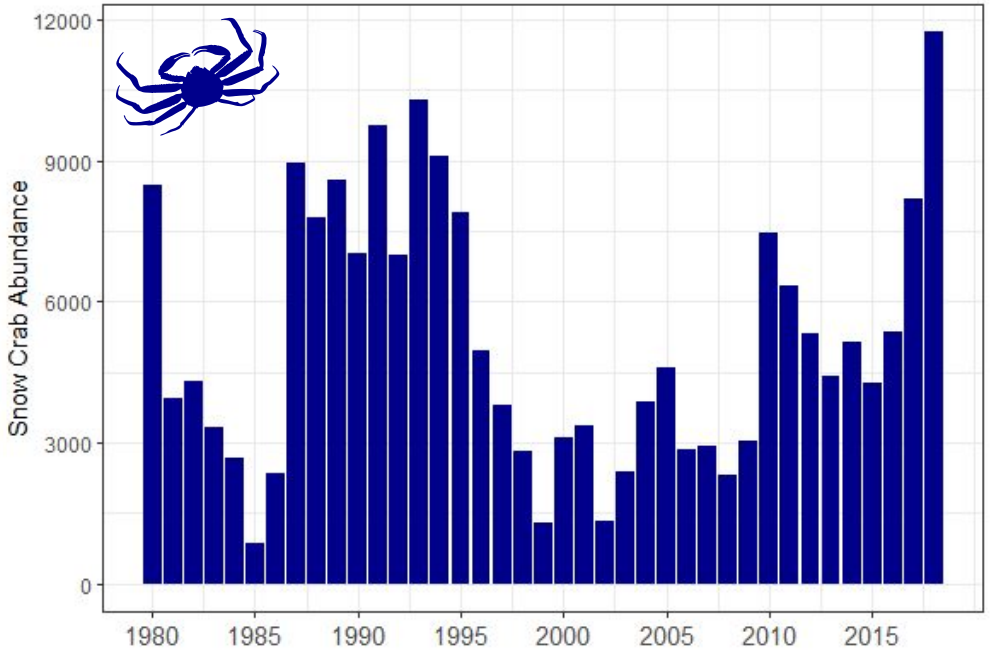
2018	2019	2020	2021	2022	2023	2024



Record high snow crab recruitment on NOAA EBS bottom trawl survey



Start of a marine heatwave in the Bering Sea

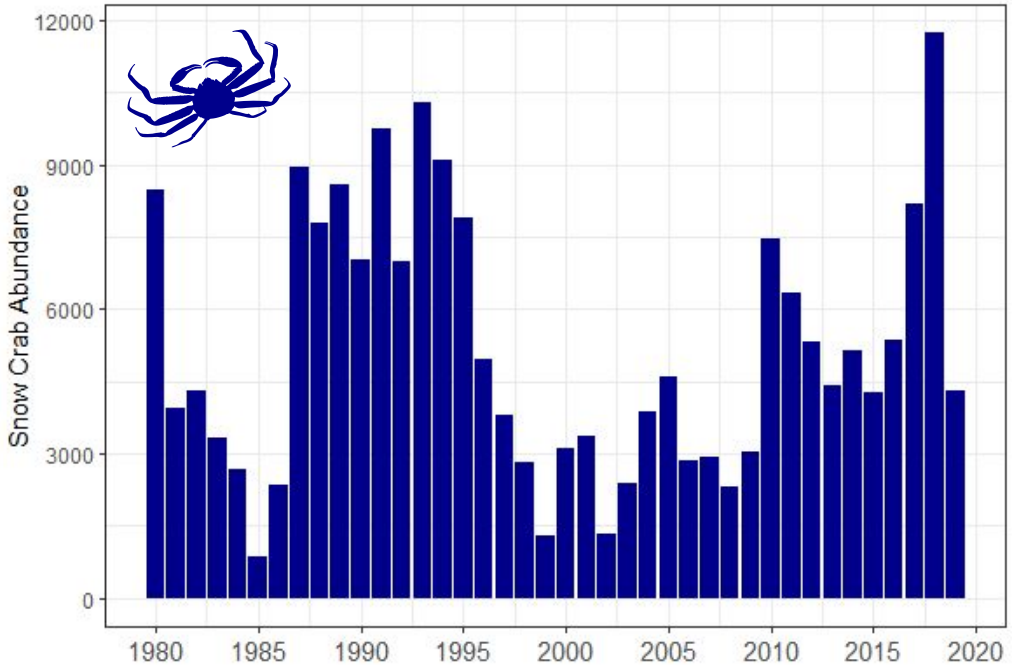


2018	**2019**	2020	2021	2022	2023	2024

2018 immature snow crab recruitment pulse didn't materialize in 2019

Marine heatwave continues in the Bering Sea

TWO RED FLAGS

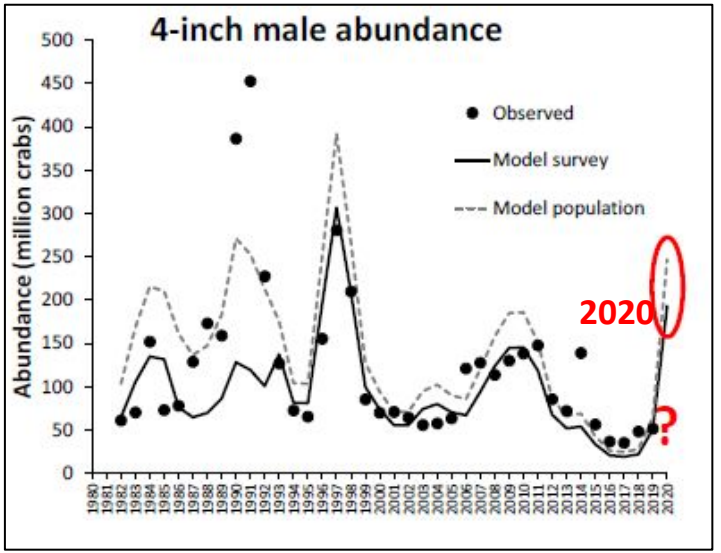


2018	2019	**2020**	2021	2022	2023	2024

Cancellation of the NOAA bottom trawl survey due to COVID-19

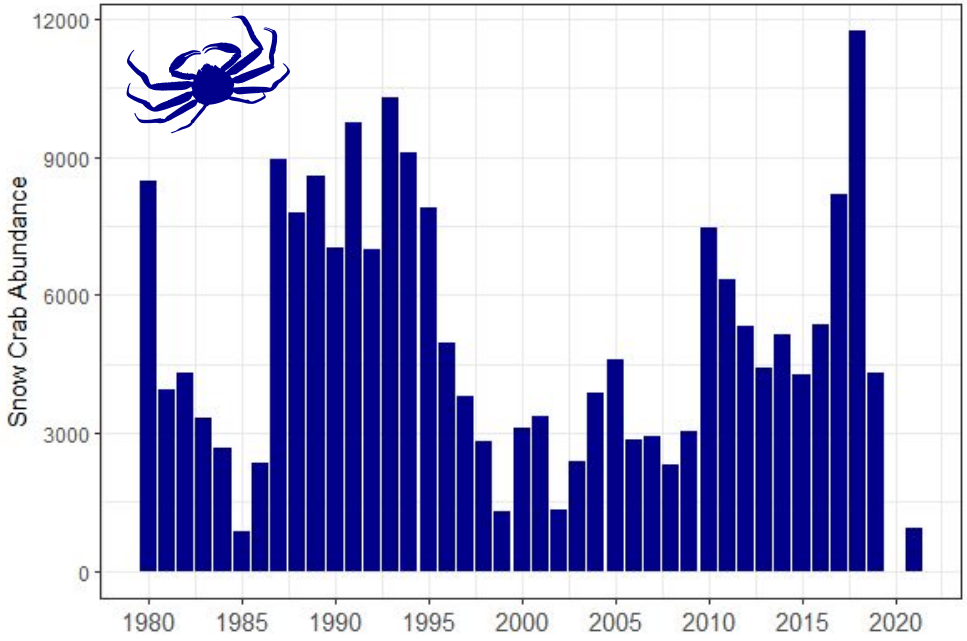
?

Substantial uncertainty in stock status
Assessment model suggests ~4x increase in mature male biomass



Snow Crab SAFE, Szuwalski 2020

2018	2019	2020	**2021**	2022	2023	2024



Snow crab population collapse: Dramatic declines across all size classes

88% reduction in TAC from 2020

What happened? The current state of knowledge

RESEARCH ARTICLE | MARINE HEATWAVES

The collapse of eastern Bering Sea snow crab

CODY S. SZUWALSKI, KERIM AYDIN, ERIN J. FEDEWA, BRIAN GARBER-YONTS, AND MICHAEL A. LITZOW Authors Info & Affiliations

SCIENCE

RESEARCH ARTICLE

Sub-Arctic no more: Short- and long-term global-scale prospects for snow crab (*Chionoecetes opilio*) under global warming

Darrell R. J. Mullowney, Krista D. Baker, Cody S. Szuwalski, Stephanie A. Boudreau, Frédéric Cyr, Brooks A. Kaiser

Human-induced borealization leads to the collapse of Bering Sea snow crab

Michael A. Litzow[1*], Erin J. Fedewa[1], Michael J. Malick[2], Brendan M. Connors[3], Lisa Eisner[4], David G. Kimmel[4], Trond Kristiansen[5,6], Jens M. Nielsen[4,7], and Emily R. Ryznar[1]

Poor energetic condition of eastern Bering Sea snow crab during a population collapse and marine heatwave

Erin J. Fedewa[1], Louise Copeman[2] and Michael A. Litzow[1]

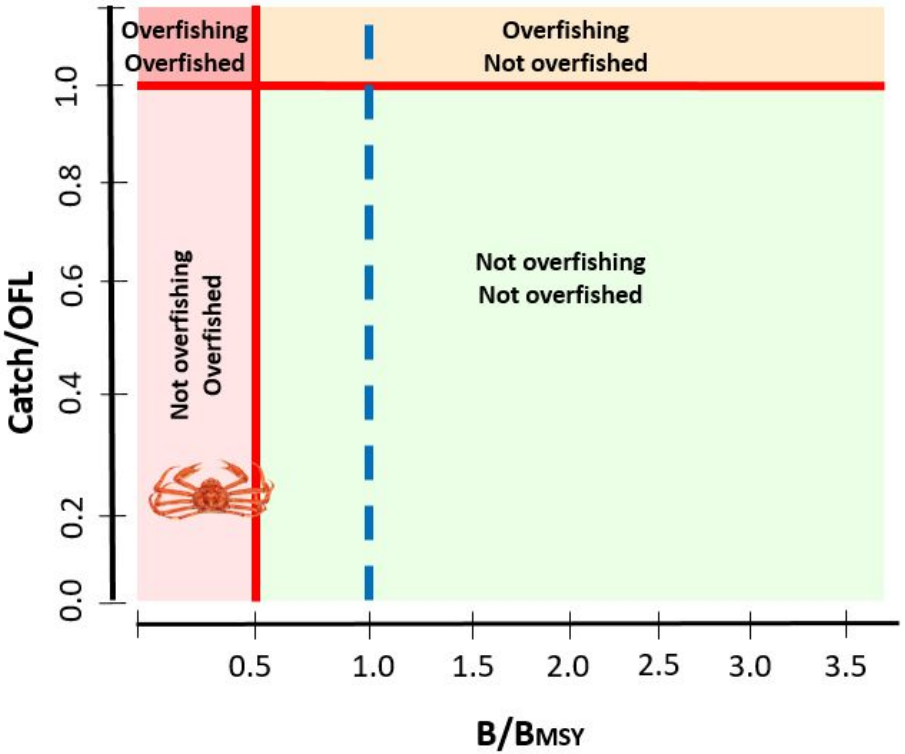
Multiple studies have linked the snow crab population collapse to a 2018 - 2019 Bering Sea marine heatwave

Increased metabolic demands, decreased spatial extent, and declines in body condition suggest starvation may have played a role

Snow crab are an ice-associated species, and snow crab productivity will likely decline alongside the loss of Arctic conditions in the Bering Sea

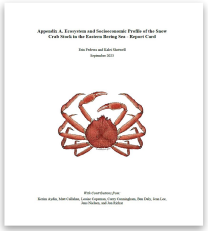
What did the response look like?

2018	2019	2020	2021	**2022**	2023	2024



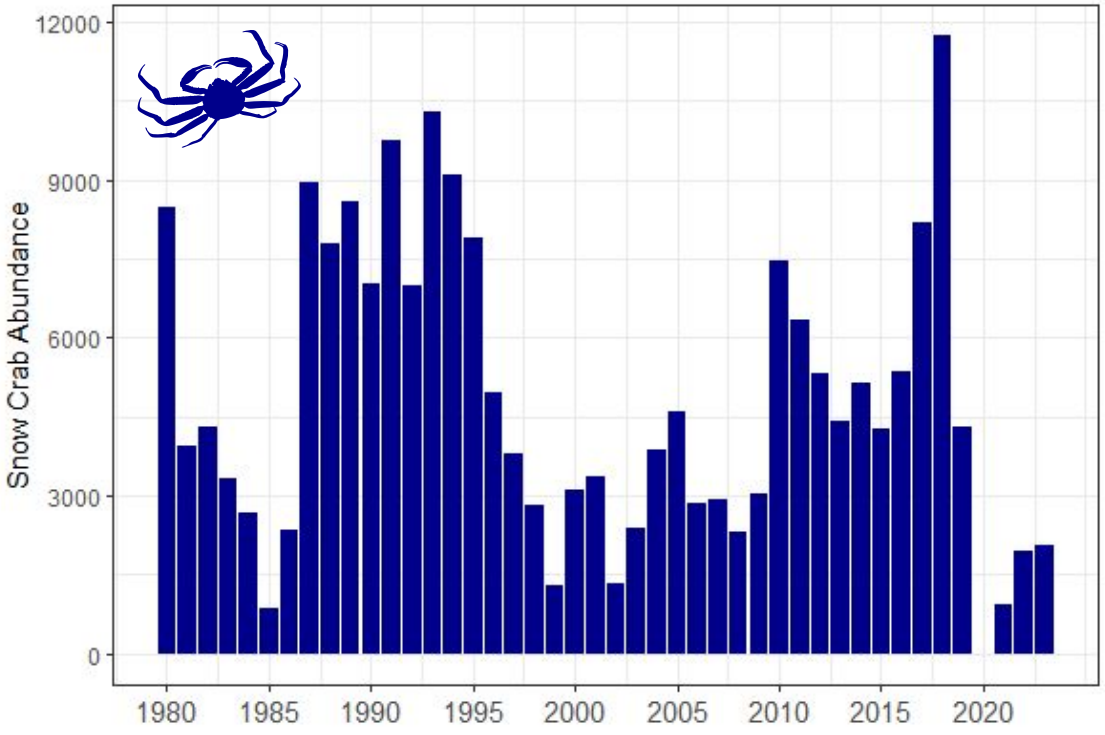
Continued declines in mature male biomass

2022-2023 Snow Crab Fishery closed for the first time in history, stock declared overfished (33% of B_{MSY})



Snow Crab Ecosystem and Socioeconomic Profile (ESP) developed

2018	2019	2020	2021	2022	**2023**	2024



2023-2024 Snow Crab fishery closed

New recruits, but 4-5 years out from fishable size

Rebuilding Plan is underway

Multiple crab fishery closures have magnified the immediate and long-term economic impacts on fishermen and crab-dependent communities

Estimated Ex-vessel revenue LOSSES

Season	Bering Sea Snow Crab	Bristol Bay Red King Crab	TOTAL
2021/22	$94M	$51M	**$145M**
2022/23	$133M	$51M	**$184M**
2023/24	$133M	$35M	**$168M**
SUM	**$360M**	**$137M**	**$497M LOSSES**

- Lost jobs in the harvesting and processing sector
- Lost revenue for communities and support businesses
- Lack of timely disaster response disproportionately harming independent harvesters, small businesses, and remote communities

Crab Economic SAFE, Alaska Bering Sea Crabbers

Were there any lessons learned?

MANY! And likely more to come…….

1) Even well-managed populations can collapse, and climate change causes unanticipated surprises

2) Stakeholders should accelerate adaptation planning and anticipate the potential loss of traditional snow crab fishing grounds as the Bering Sea continues to warm

3) Projections based on historical assumptions and population dynamics are not reliable when future conditions do not resemble past conditions in the Bering Sea

4) Surveys are critically important, and annual surveys in the northern Bering Sea should be prioritized

5) Climate change planning needs to also focus on *near-term* actions to stabilize fishing fleets, offer opportunities for diversification, and provide timely fishery disaster assistance

6) Don't change reference points

Fish the stocks that flourish harder, allow time to adapt for stressed populations.

7) Look for ways to relieve stress on populations for which management levers exist

Even if we predict outcomes perfectly, with no management lever, we can't change the outcome

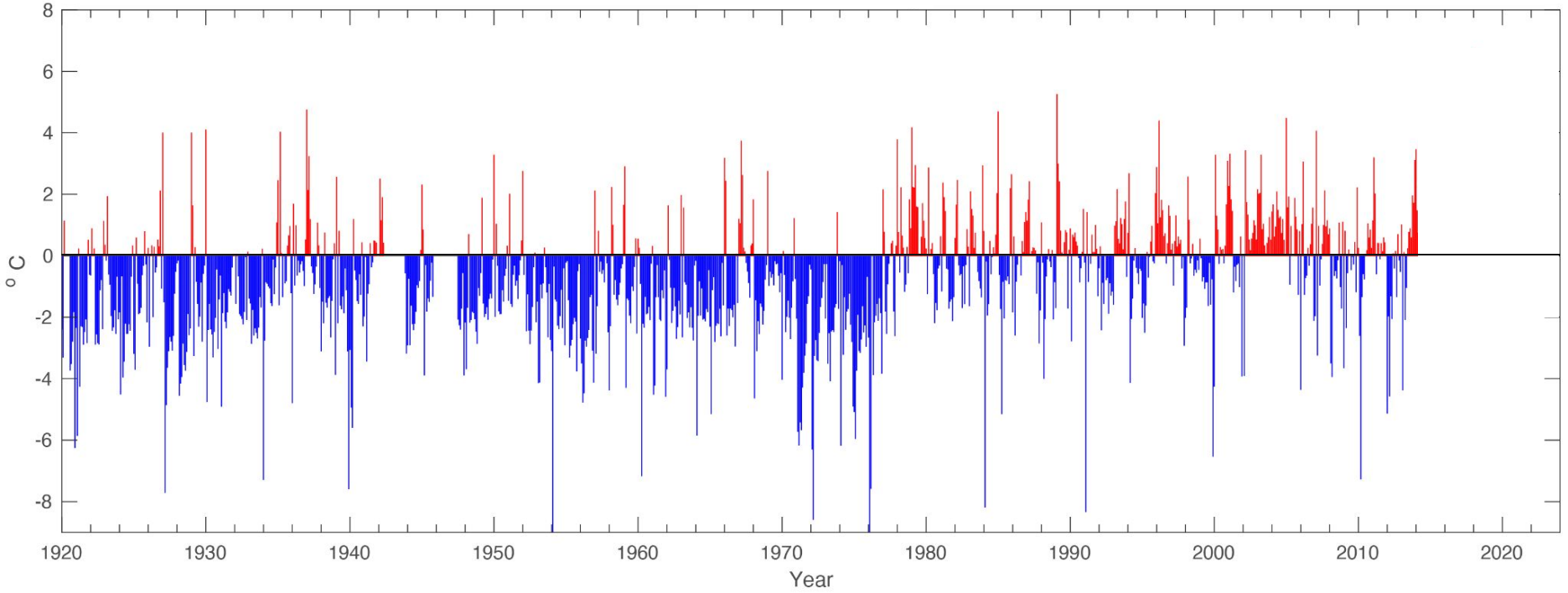
C. Szuwalski, M. Litzow, J. Goen

Rapid change in the Northern Bering Sea

Elizabeth Siddon, NOAA AFSC
Contributions from: Jim Overland, Muyin Wang, Rick Thoman, Nick Bond,
Kelly Kearney, Frank Mueter, Stephani Zador,
and the AFSC Groundfish Assessment Program

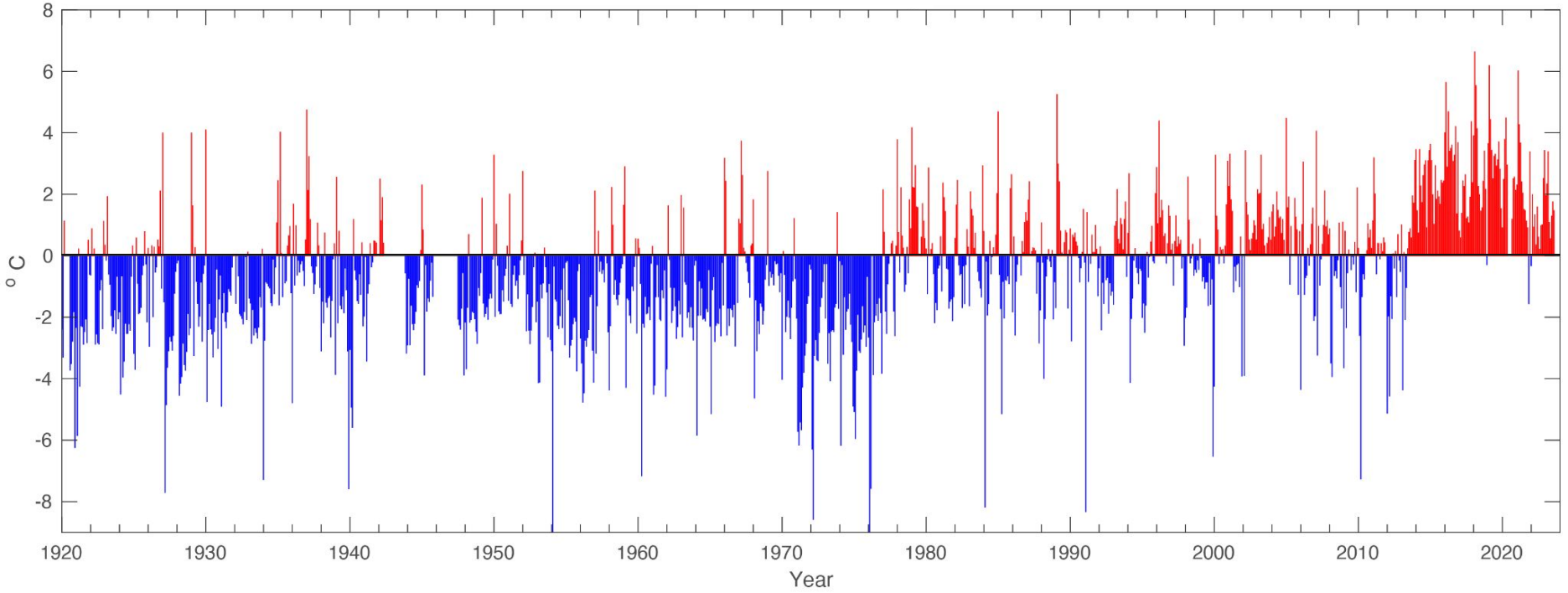
What happened?

The Bering Sea has had periods of warm and cold



Overland & Wang, PMEL

Recent warm period was greater in duration and magnitude



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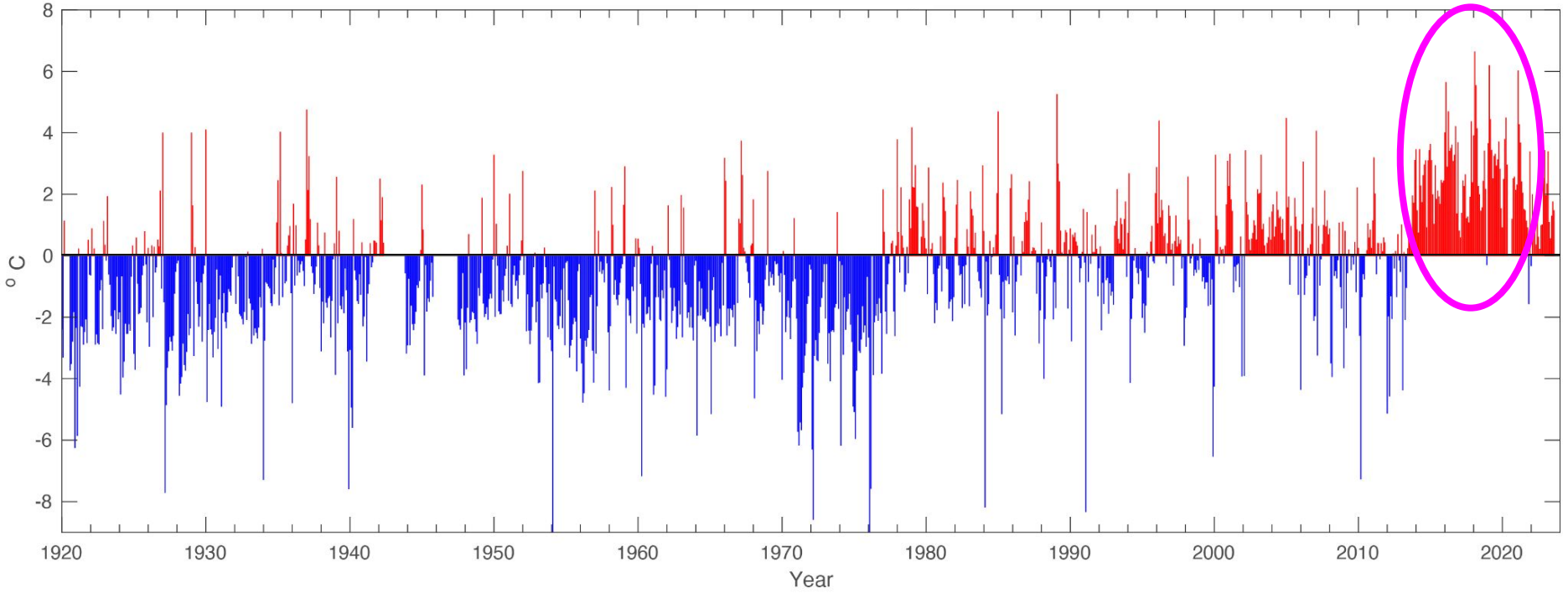
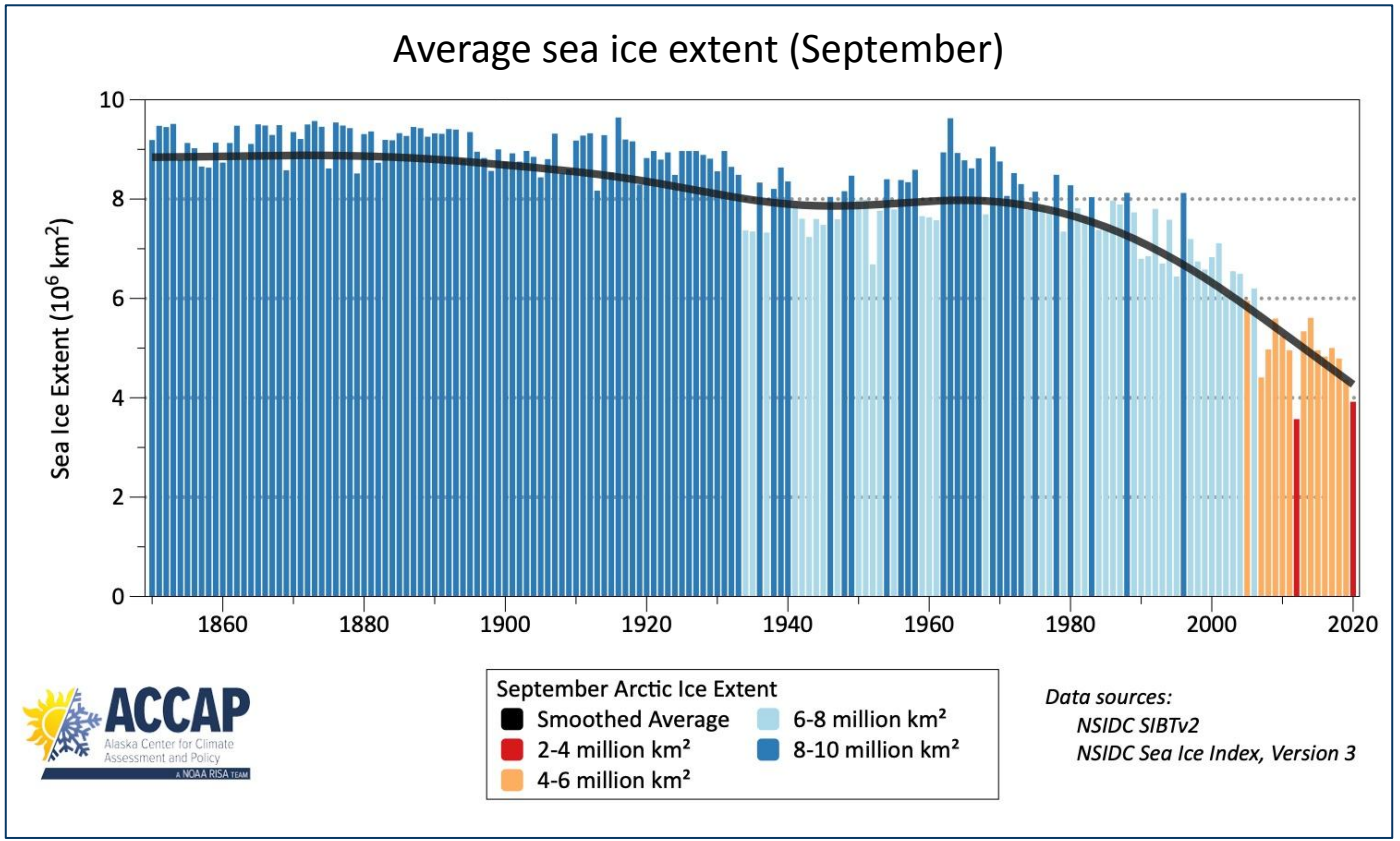


Overland & Wang, PMEL

Warming temperatures have resulted in less sea ice extent



Thoman

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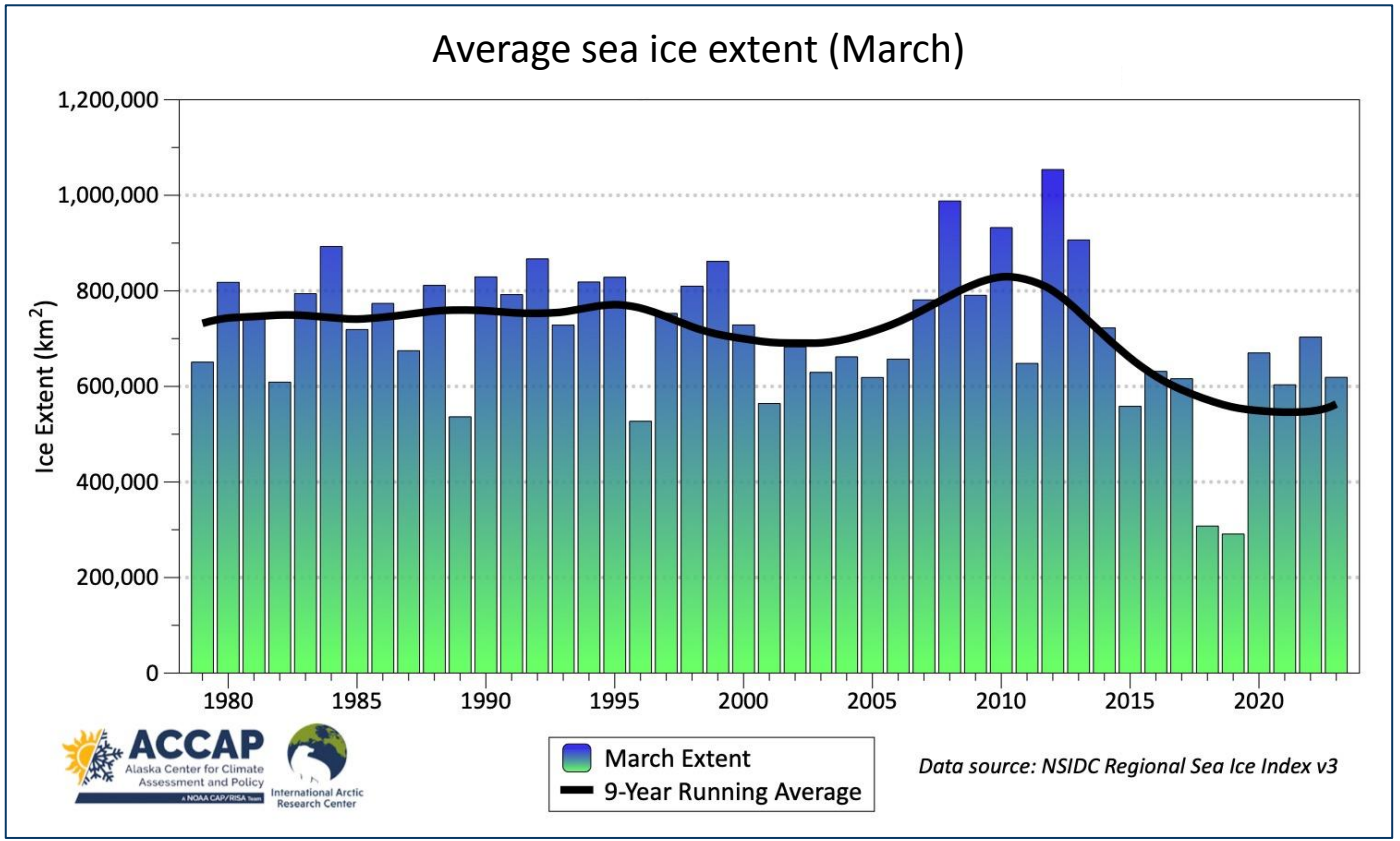
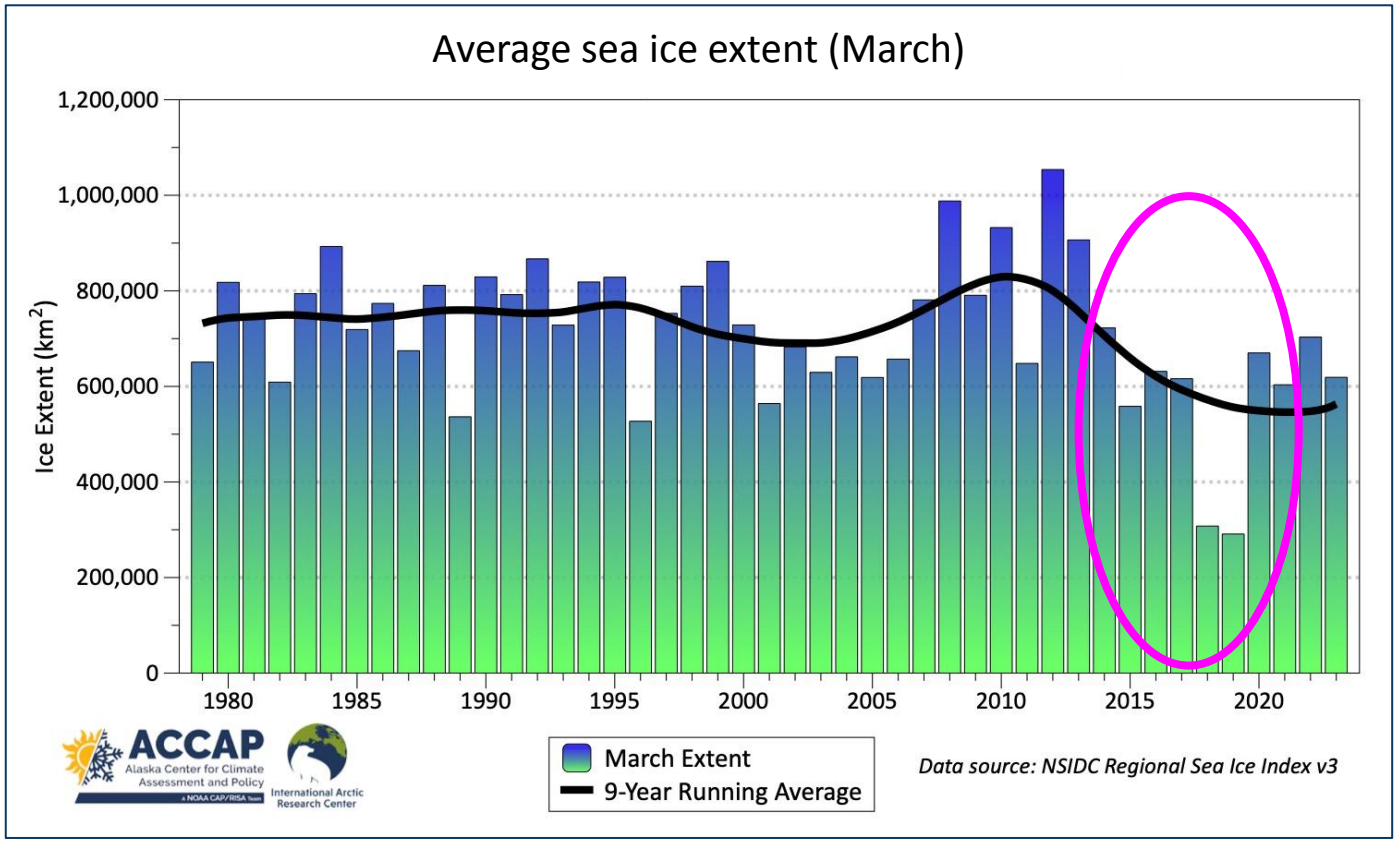


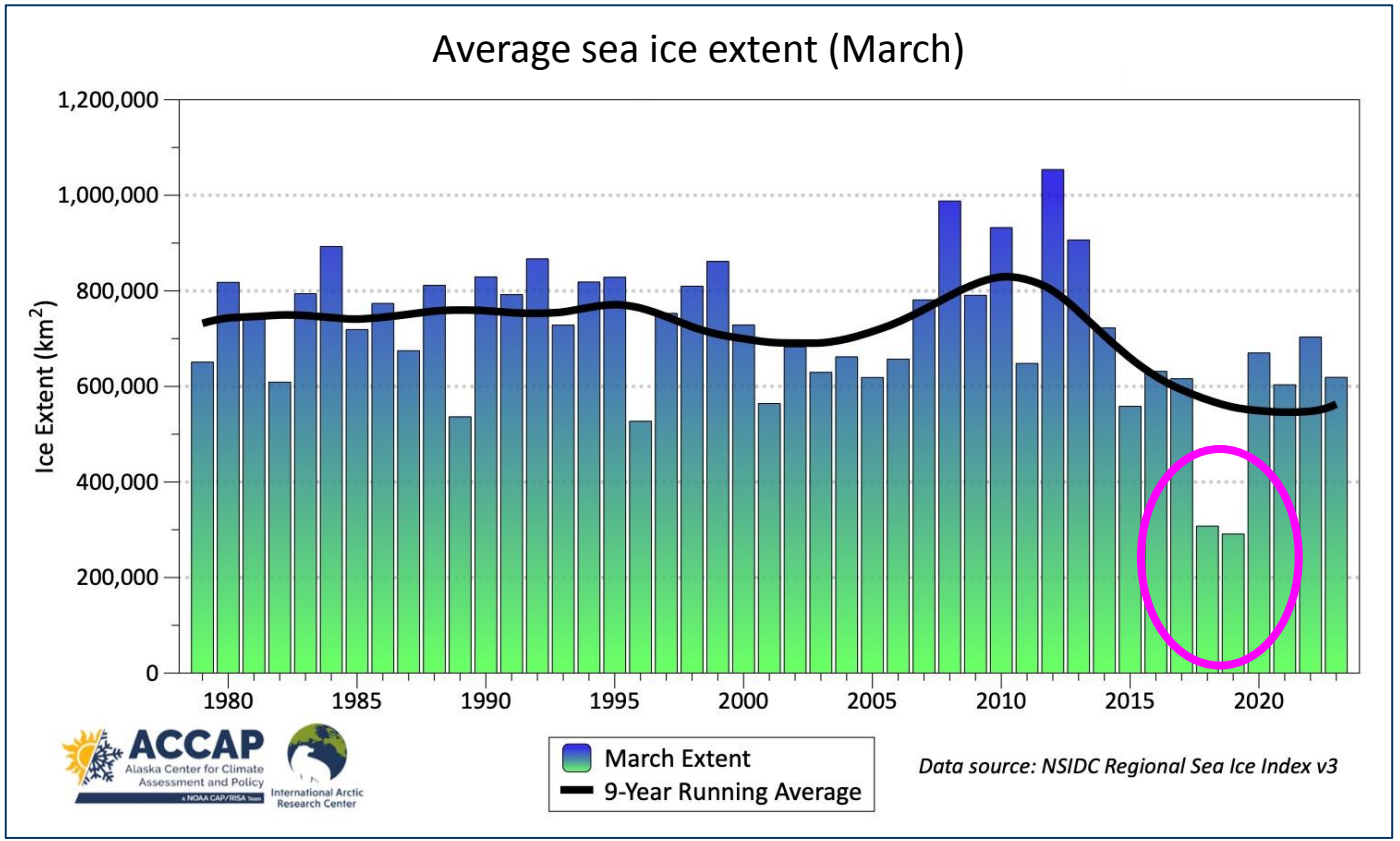
Thoman, UAF

Warming temperatures have resulted in less sea ice extent



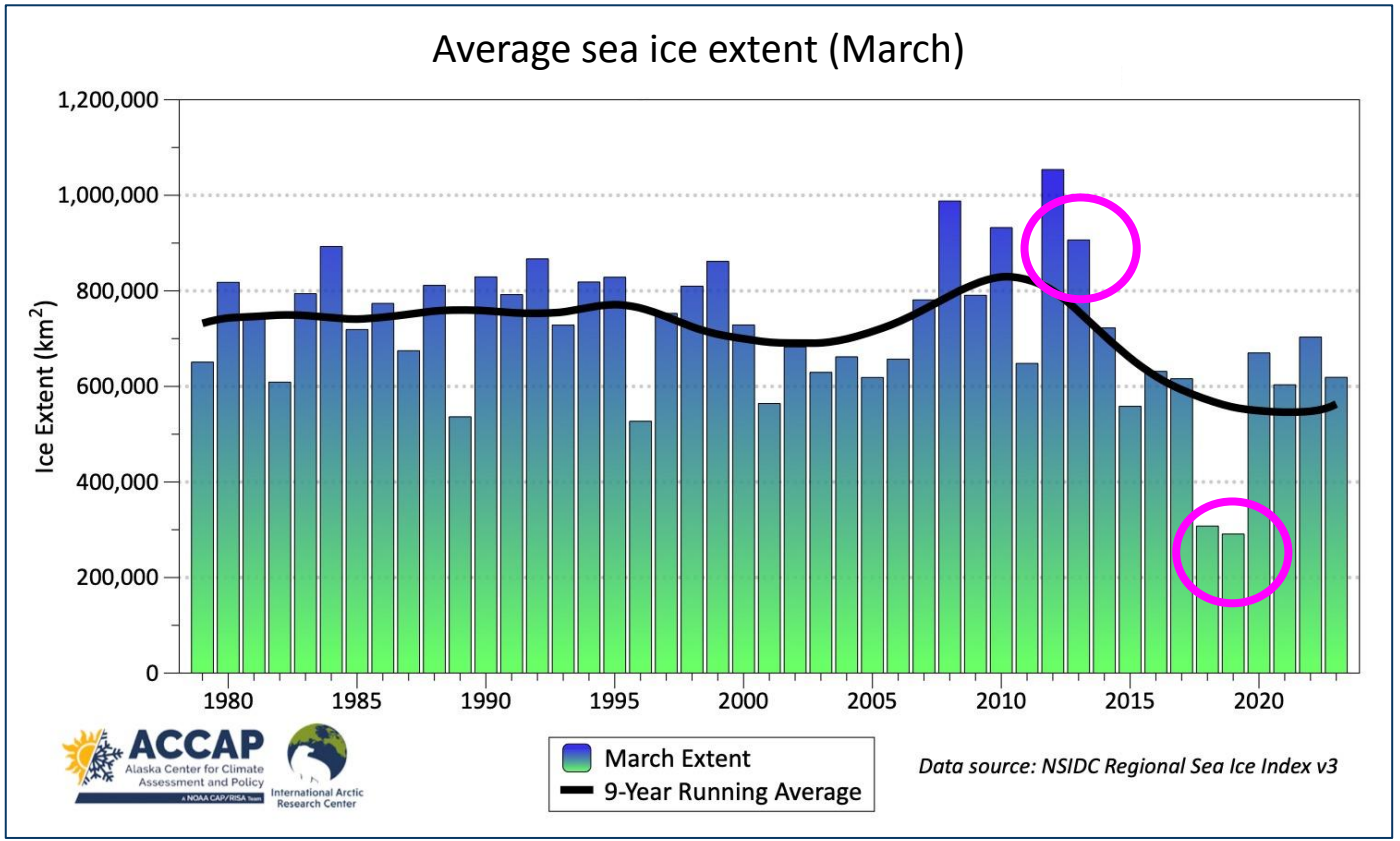
Thoman, UAF

Unprecedented low sea ice in 2018 and 2019



Thoman, UAF

High sea ice (2013) versus low sea ice (2019)



Thoman

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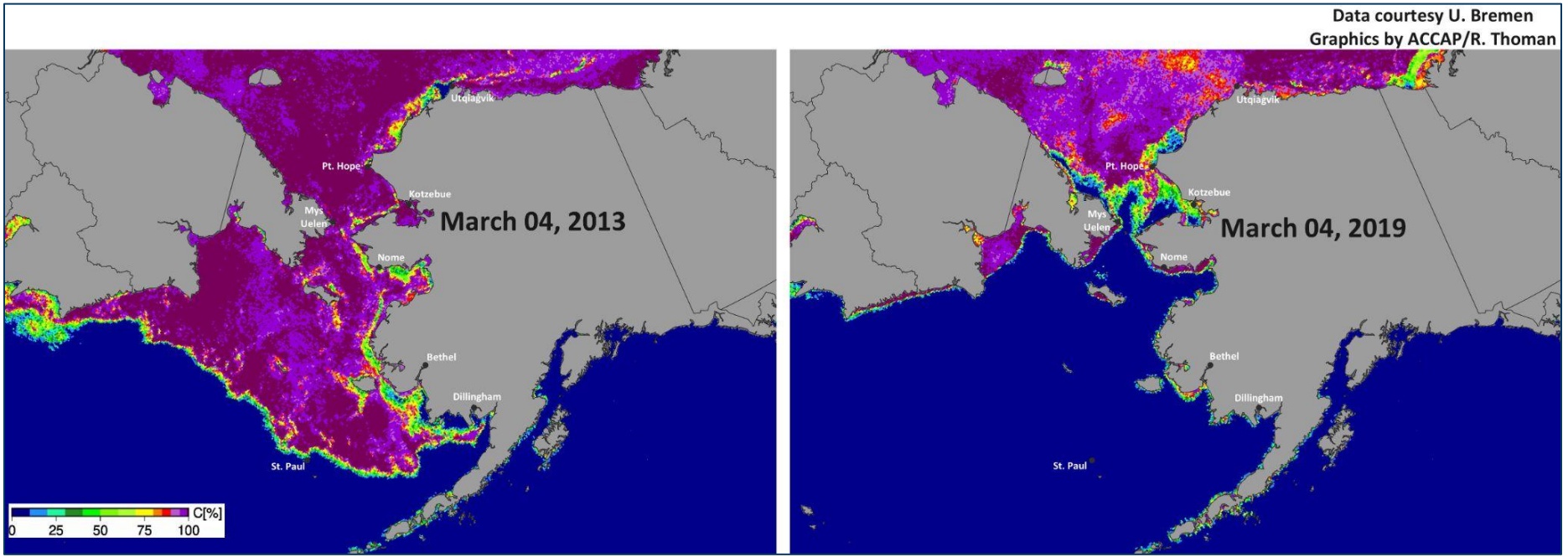
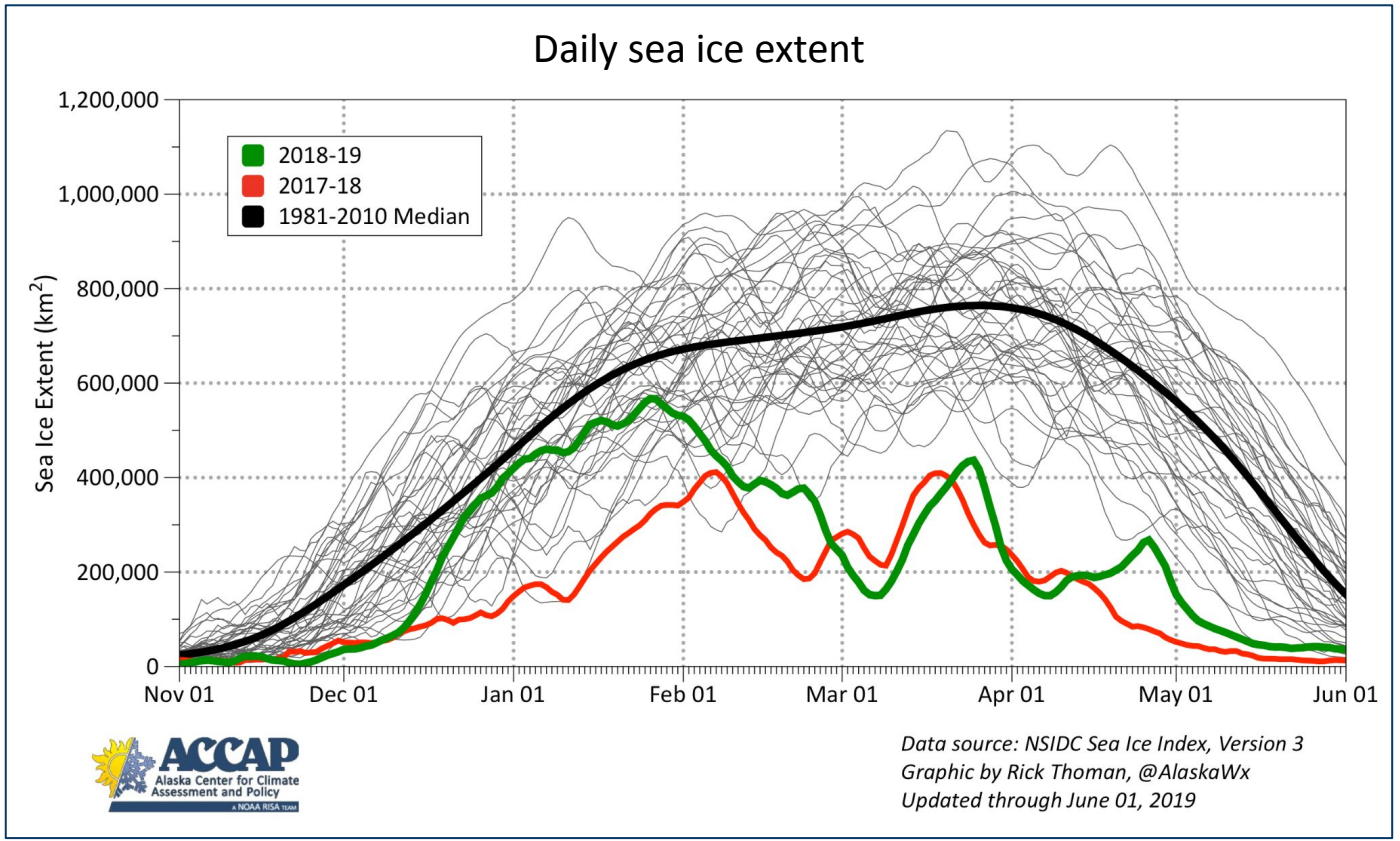
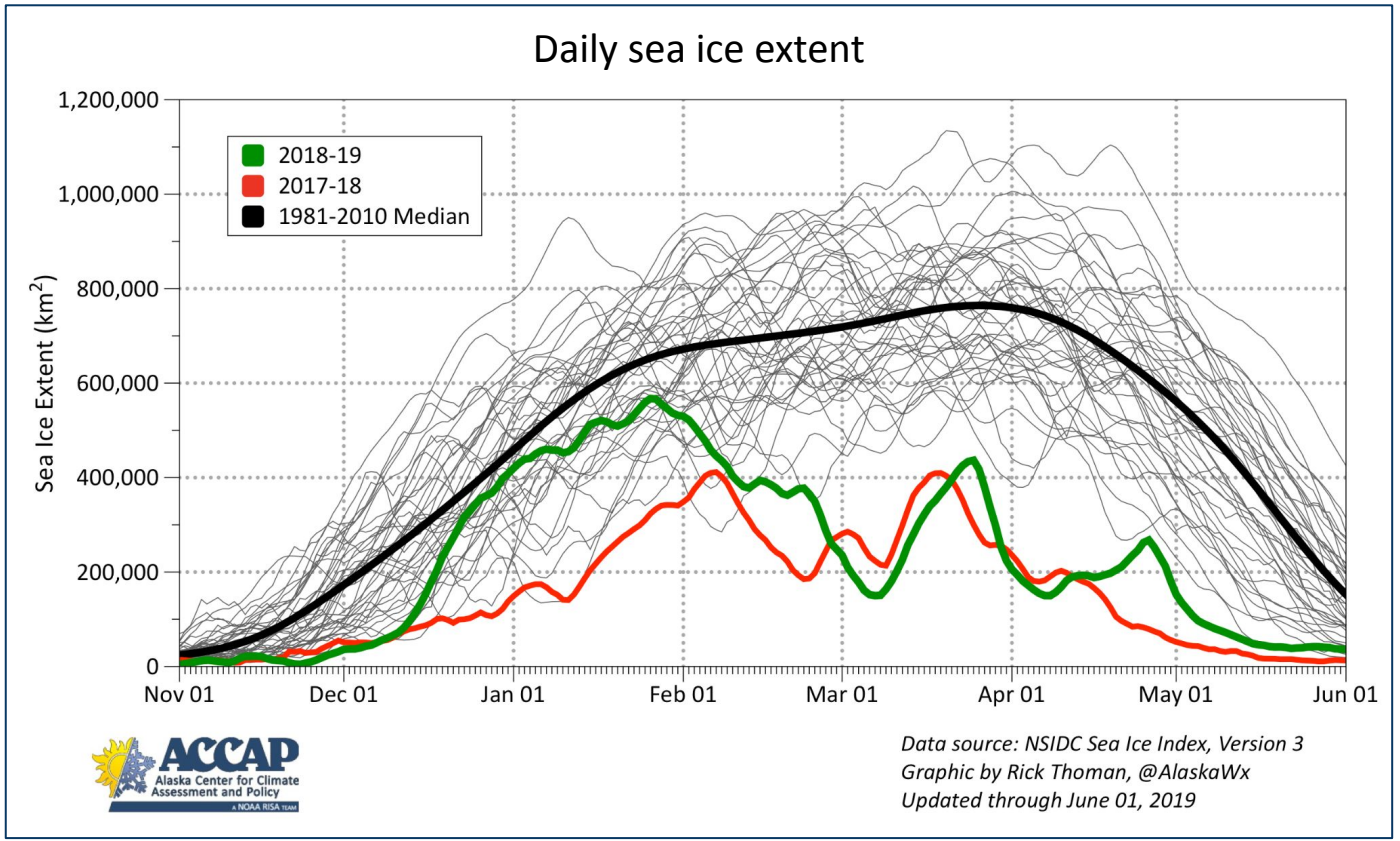


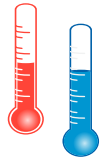
Thoman

How did 2018 and 2019 happen?

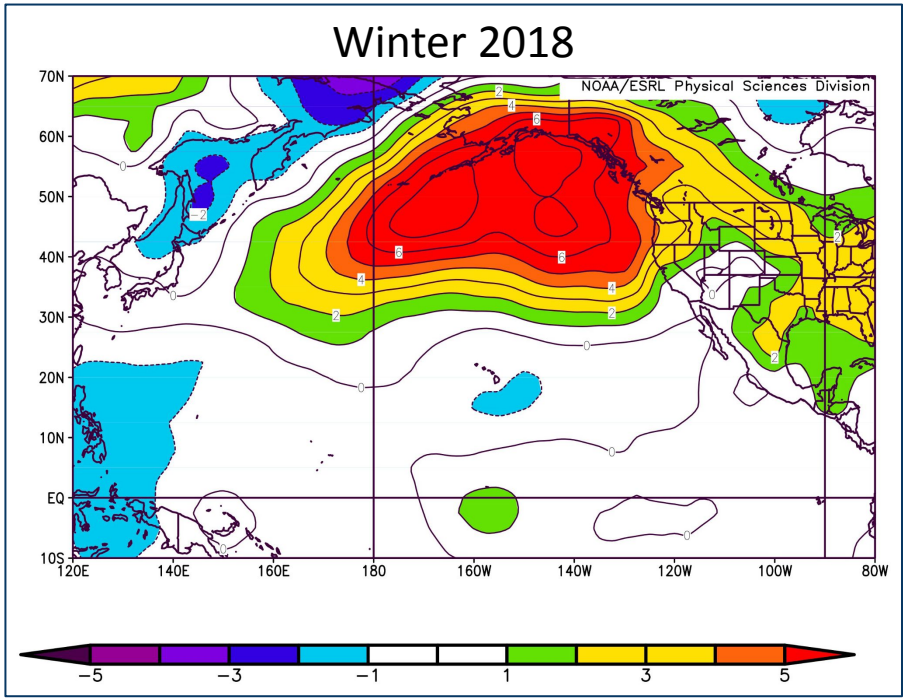


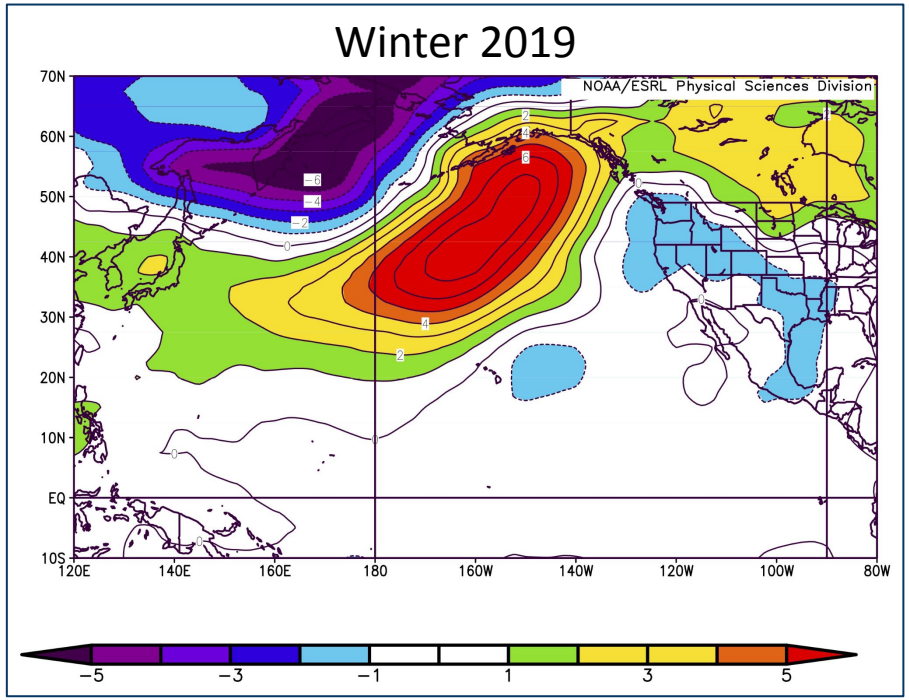
It takes two to tango





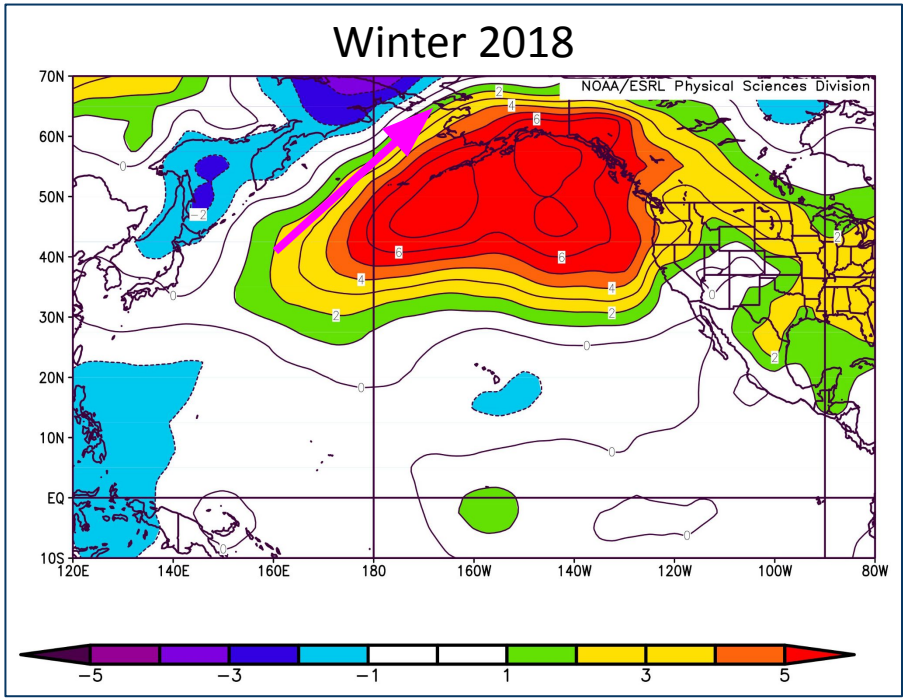
Winter winds from the south prevented sea ice

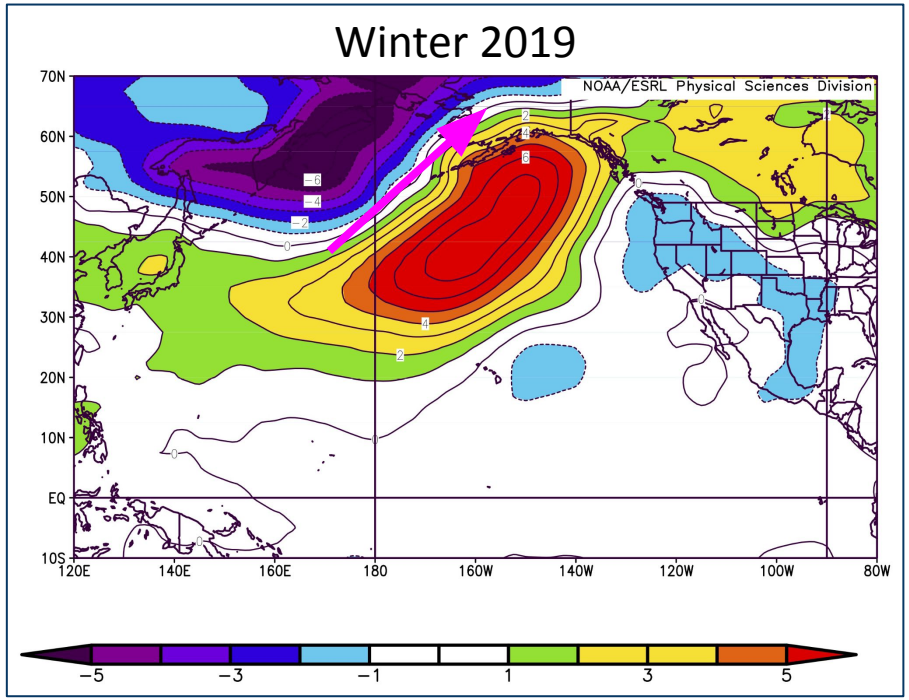




Bond, CICOES

Winter winds from the south prevented sea ice

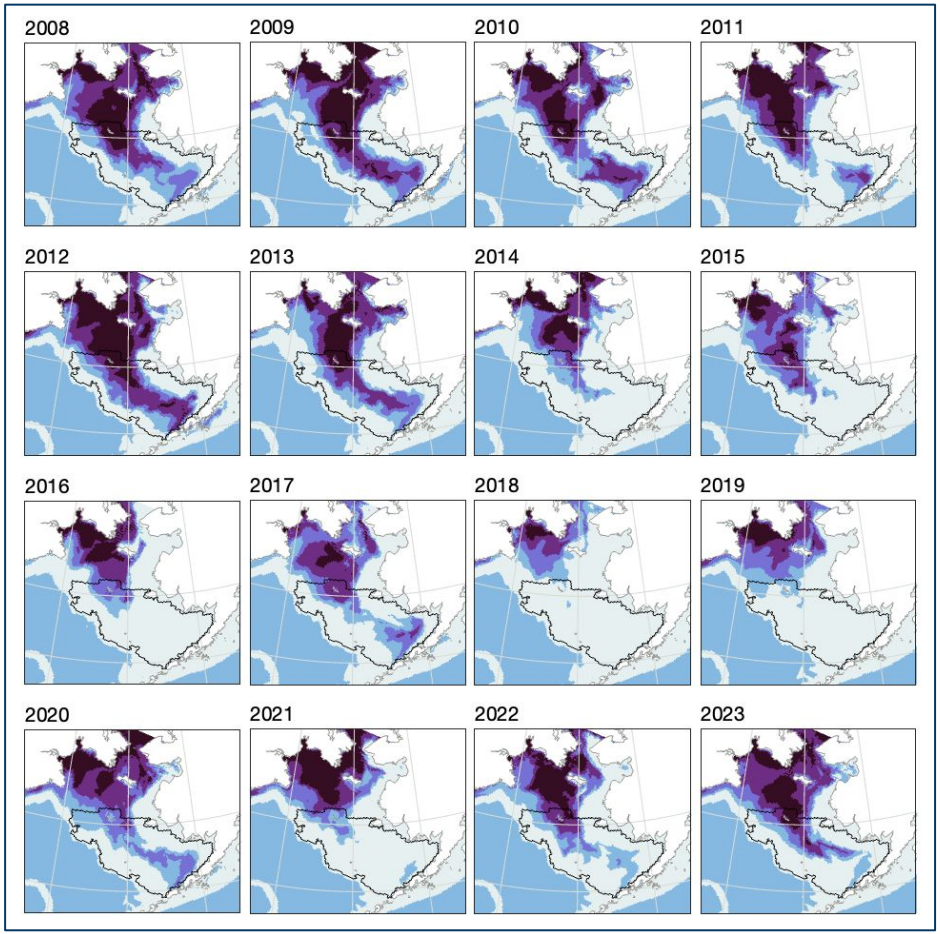




Bond, CICOES

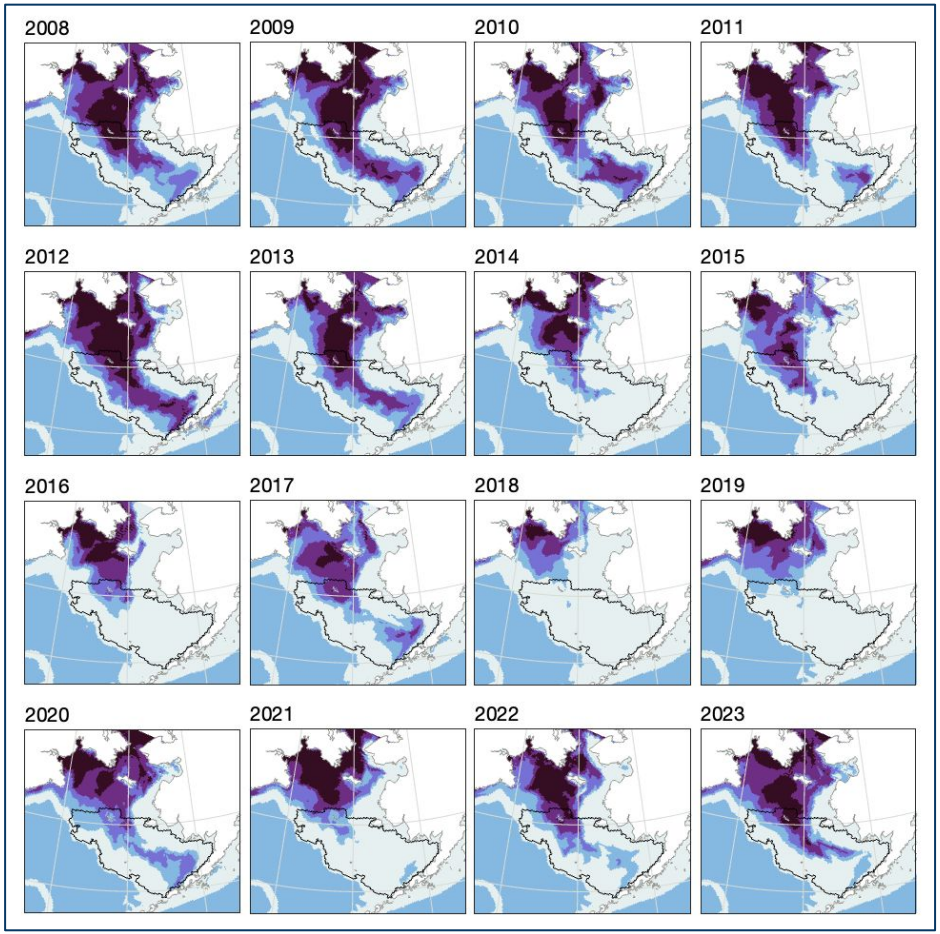
What information was available?

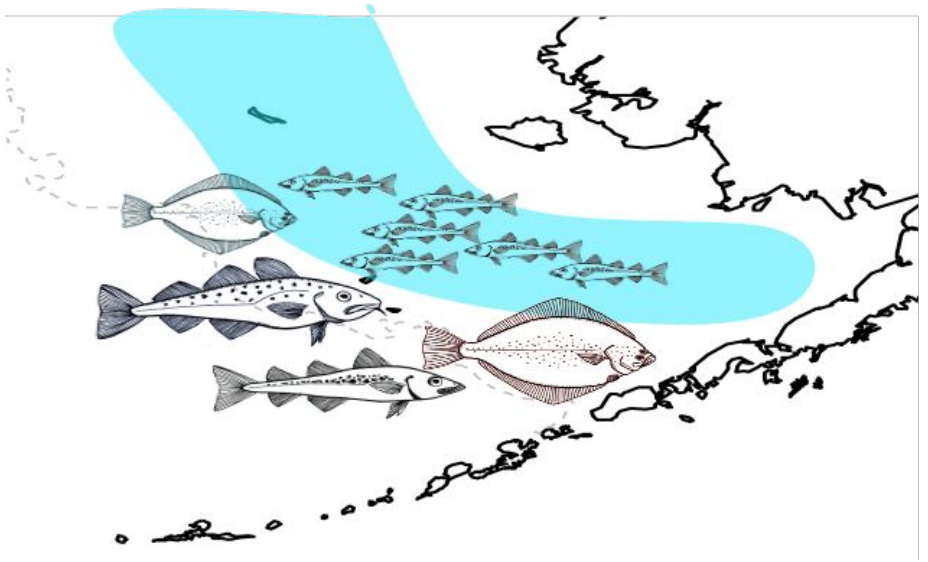
Cold pool extent (a footprint of winter sea ice extent)



K. Kearney, AFSC

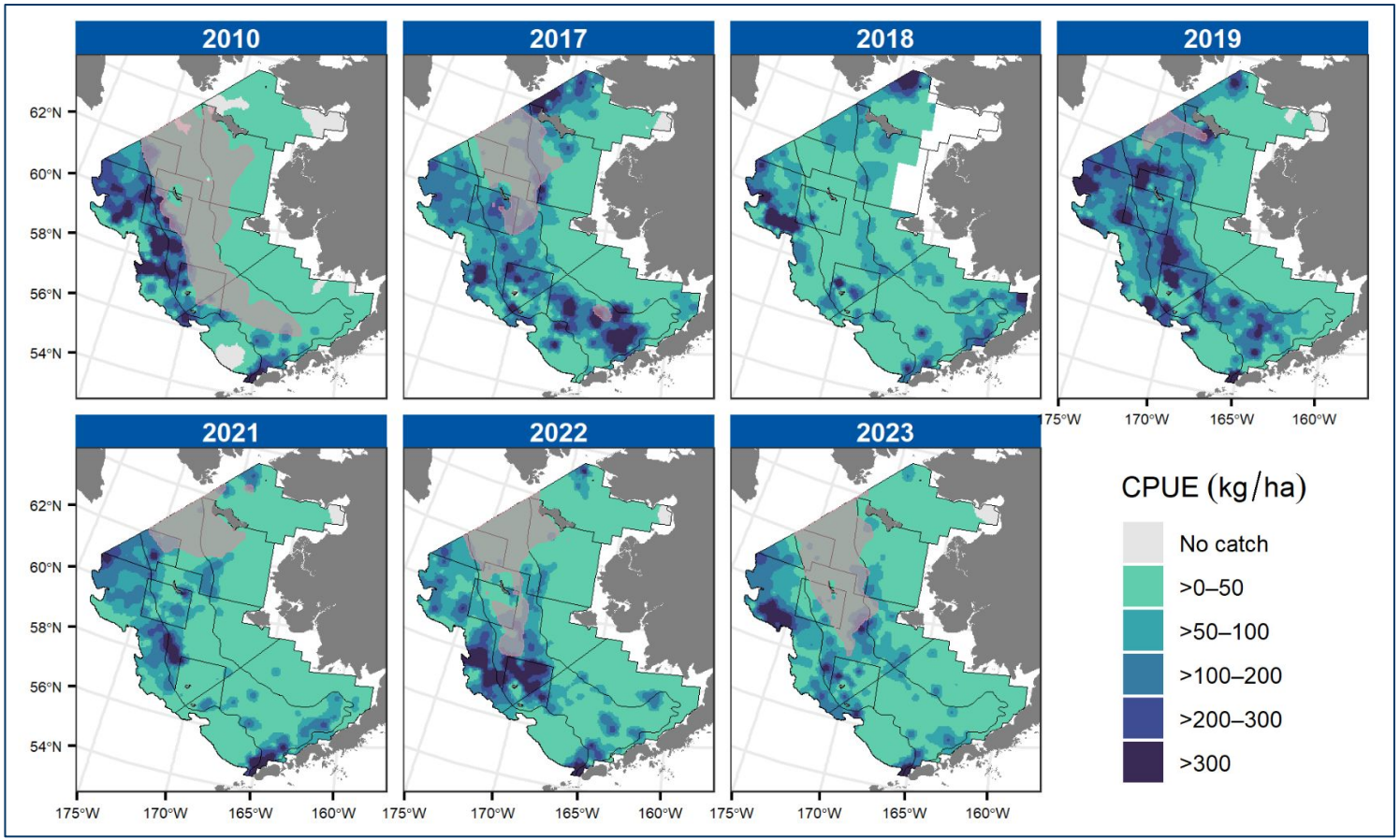
The cold pool structures the Bering Sea ecosystem





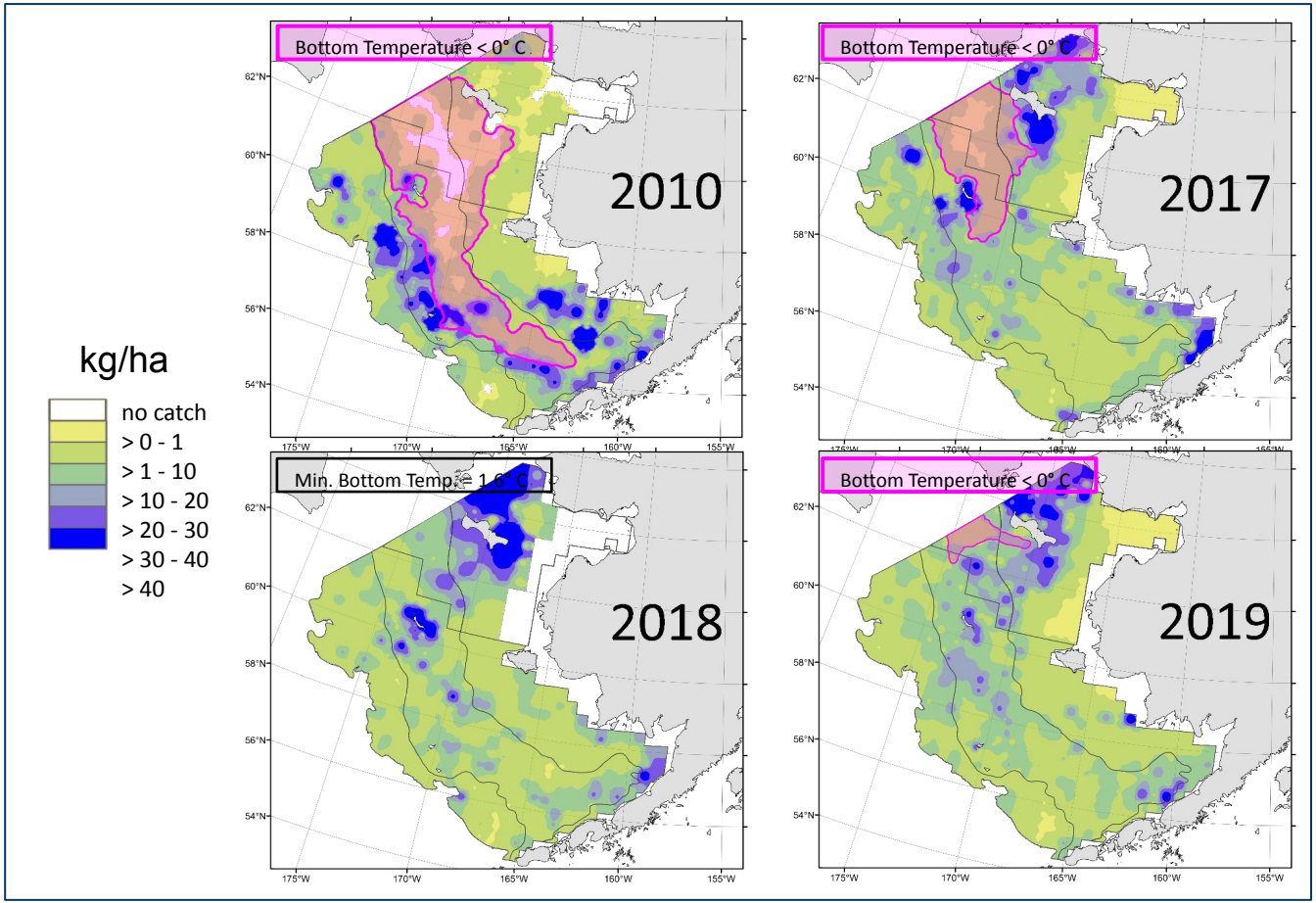
K. Kearney, AFSC

Adult walleye pollock outside the cold pool



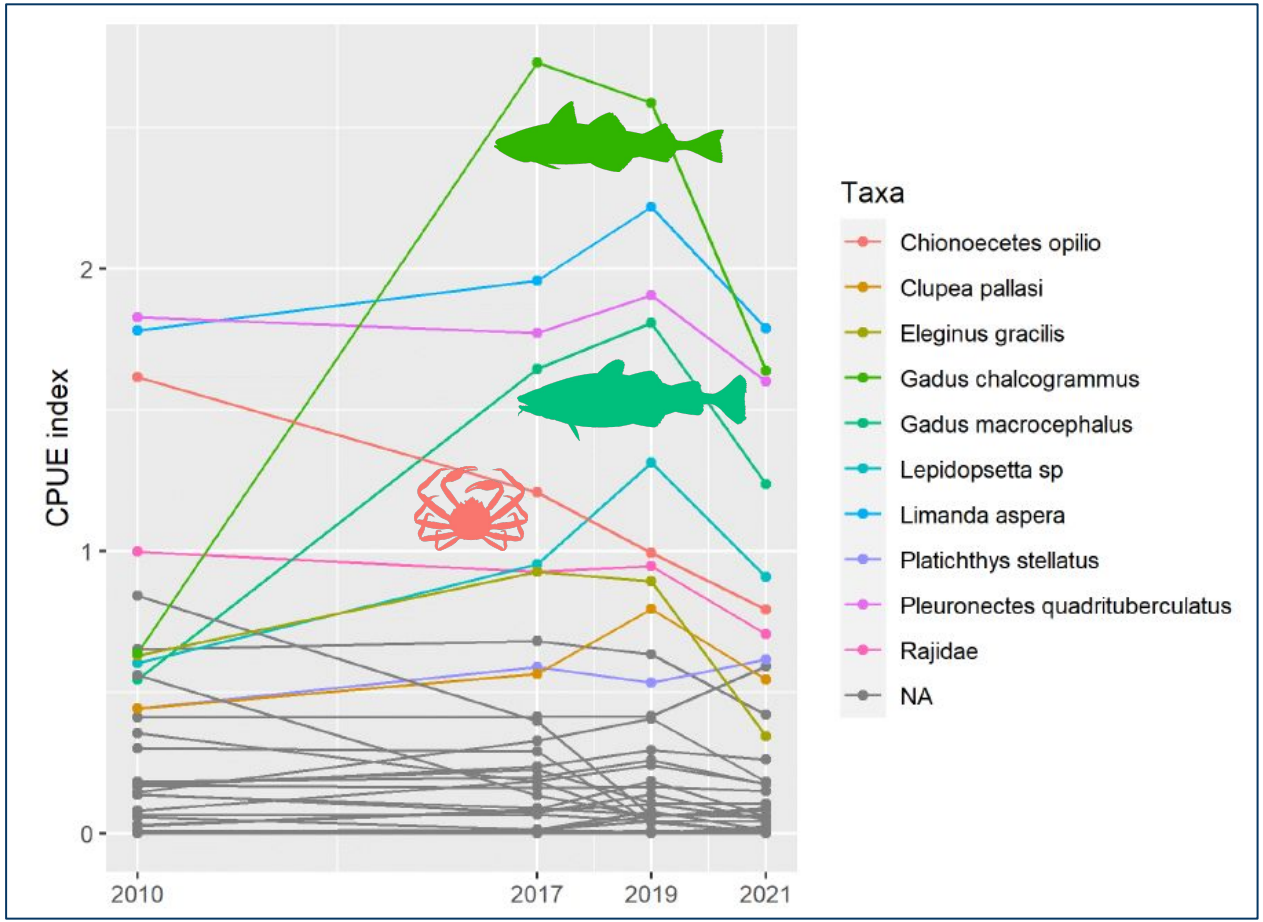
Rohan, AFSC GAP

Adult Pacific cod outside the cold pool

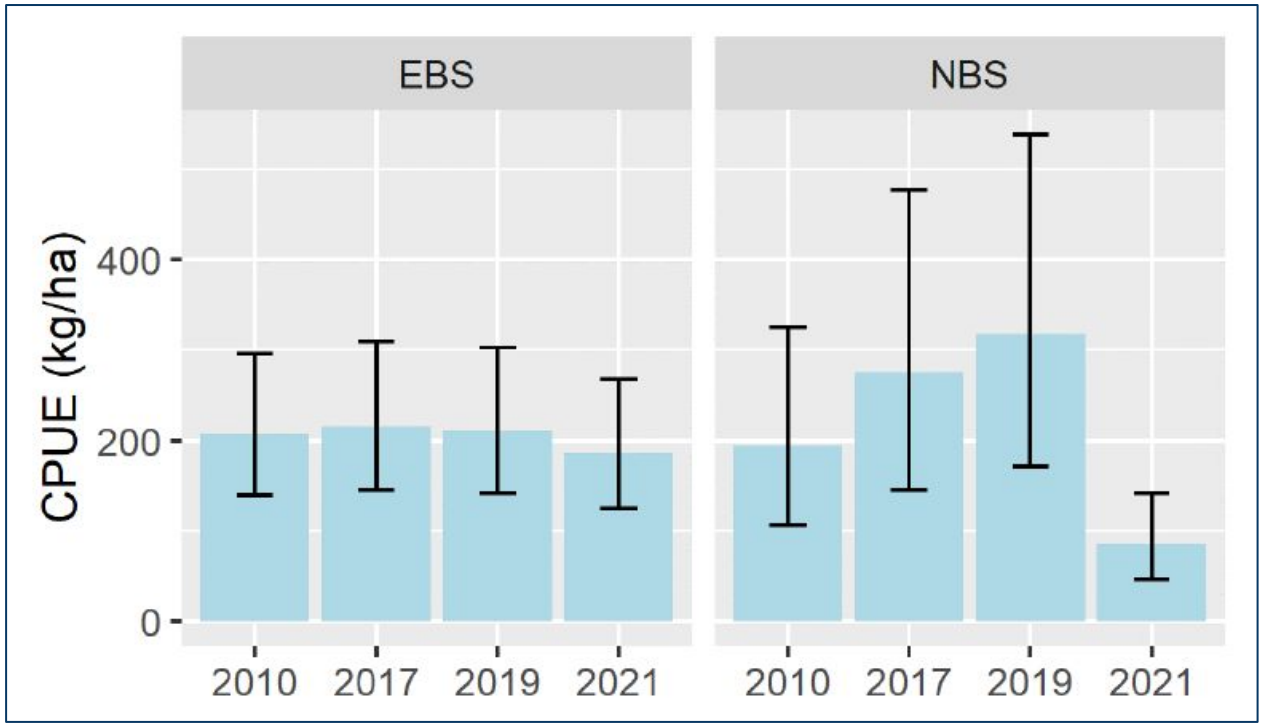


Britt, AFSC GAP

Changes in biomass in the northern Bering Sea



Mueter, UAF


EBS
NBS
CPUE (kg/ha)
400
200
0
2010
2017
2019
2021
2010
2017
2019
2021

Mueter, UAF

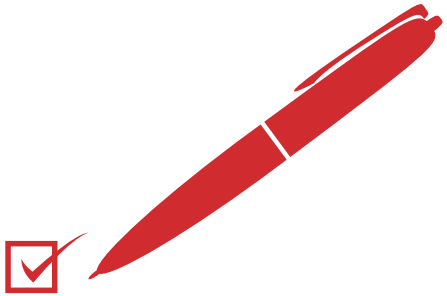
Questions about the carrying capacity of the northern Bering Sea

- 2019-2023 gray whale Unusual Mortality Event
  - attributed to ecosystem changes in sub-Arctic and Arctic feeding areas

Photo taken by Sara Germain

- 2019 Short-tailed shearwater die-off event
  - Feed in the northern Bering Sea in summer (primarily on zooplankton) before migrating to southern ocean for breeding

Response



Community impacts & adaptations

Loss of sea ice as platform for ice seals, hunting/fishing, travel; **increased fishing vessel activity** and marine debris events; **unusual mortality events** (ice seals, short-tailed shearwaters, gray whales).

Scientific adaptations

Northern extension of the NOAA bottom trawl survey became a more regular survey used to inform crab and groundfish assessments in the Bering Sea.

Management adaptations

North Pacific Fishery Management Council accepted new stock assessment models that included northern Bering Sea survey data beginning in 2019; developed Western Alaska Community Development Quota program for commercial fisheries.

Overland et al., 2024

Consideration of qualitative ecosystem information can have quantitative impacts in the decision making process

Ecosystem considerations Level 2

Reduced sea ice and cold pool extents in 2018 and 2019, PCod expanded into the NBS. Concern over carrying capacity of the NBS ecosystem due to marine mammal UMEs and seabird die-offs.

Author recommended **no reduction** in catch, which was accepted by the Council.

Lessons learned

Climate change is here

- Alaska's fisheries are already challenged by climate extremes
- 'Black swan' events are difficult to predict; we should expect large ecosystem impacts
- Ecosystem response can vary; stocks impacted may change

Impacts of climate change

- What moves north can/may move south again as sea ice returns
- Impacts can be immediate (same year), lagged (some time later), and cumulative (stronger if conditions persist)
- Similar but different responses across regions (e.g., starvation, carrying capacity)

Adaptations to climate change

- Communities often experience changes first; how best to incorporate and utilize Traditional Knowledge and Local Knowledge in the decision-making process
- Scientists provide current-year data in real-time to fisheries managers
- Managers use ecosystem information in decision-making and it can impact catch limits

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NPFMC Climate Scenarios Workshop
June 5, 2024

Sablefish Climate Case Study: Triumphs and Trials

Dana Hanselman

NOAA AFSC, Auke Bay Labs

Collaborators: Dan Goethel, Kalei Shotwell

Outline

- Sablefish background
- The Boon+Swoon Cycle
- The heat-wave “miracle”
- Assessment and management response
- Lessons learned

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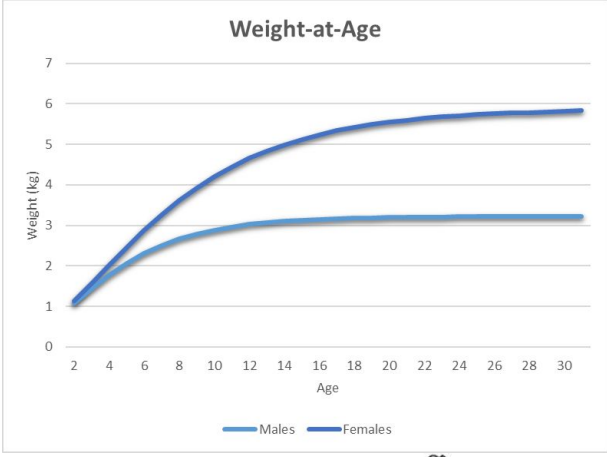
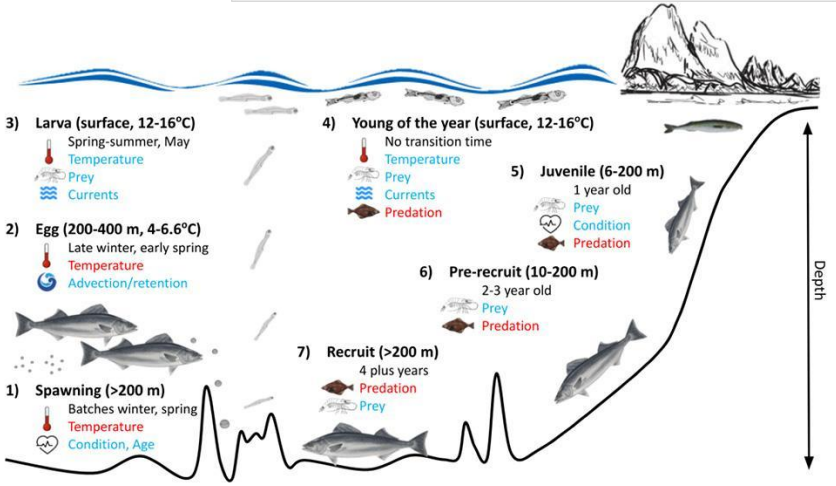
Biology

- Long-lived (>90 years), deep-dwelling (>200m) species
- Extremely high movement rates, distributed across northern Pacific from Mexico to Japan
- No genetic diversity across their range in northeastern Pacific
- Sexually dimorphic growth
- Fully mature at ~age-12
- Juveniles migrate from shallow inshore to deep offshore habitat





Shotwell et al. (2023)

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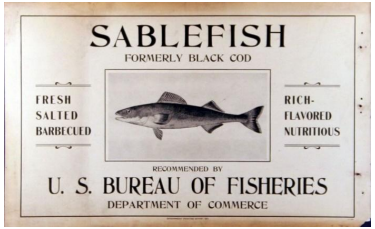
Management and Fishery

- Sablefish, because of their extensive movement are the only stock assessed Alaska wide
- Quota is apportioned to management region
- Traditionally mostly hook and line and GOA-centric, but recently has made a dramatic move to longline slinky pots because of whales
- Annual longline survey and assessment



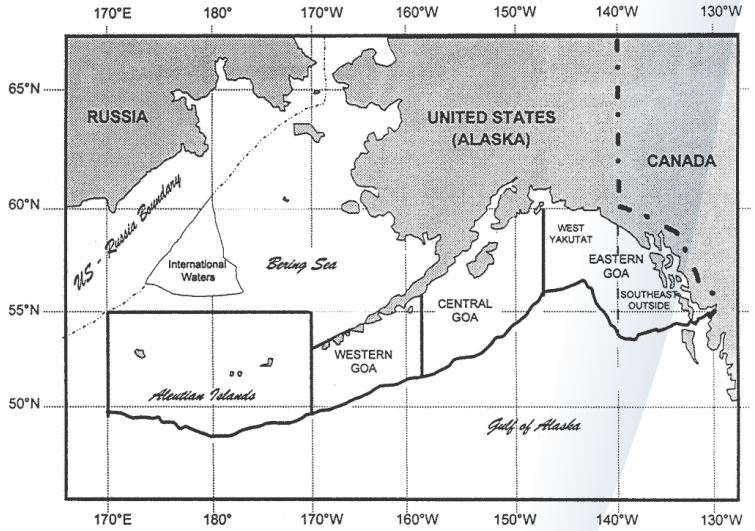


Figure 14 to Part 679. Sablefish Regulatory Areas and Districts

NOTE:Refer to Figures 1 and 3 for coordinates.

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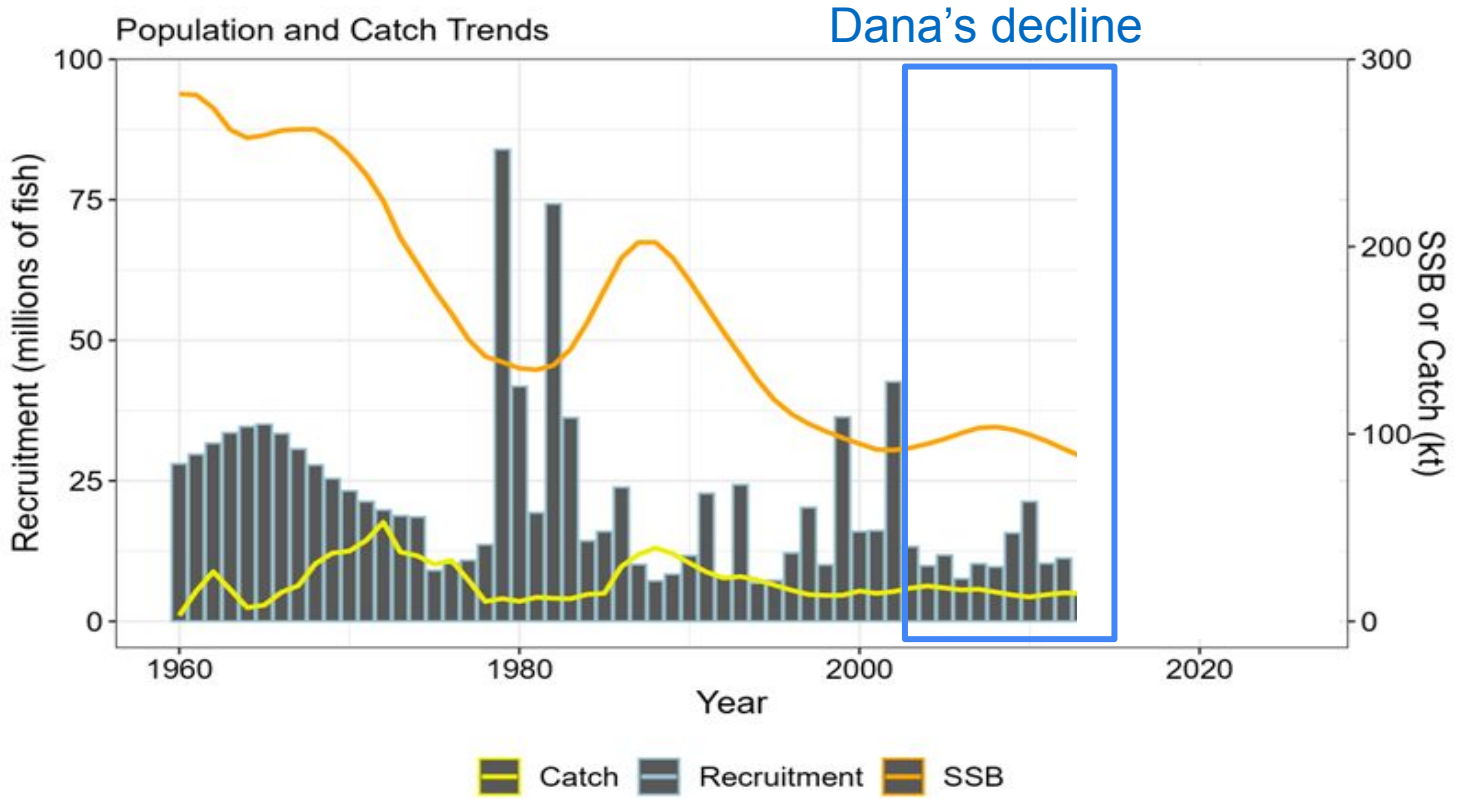
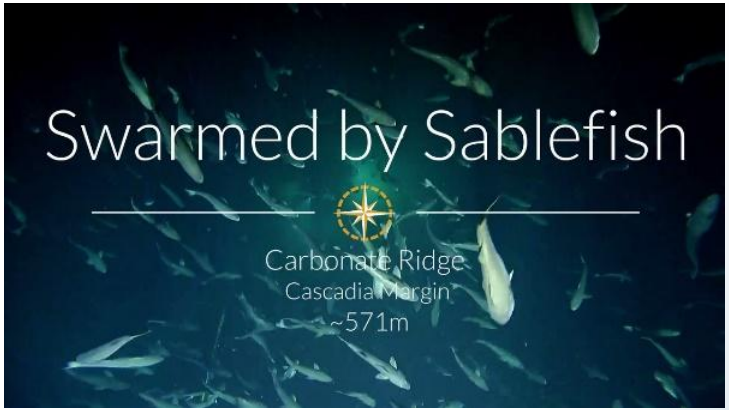
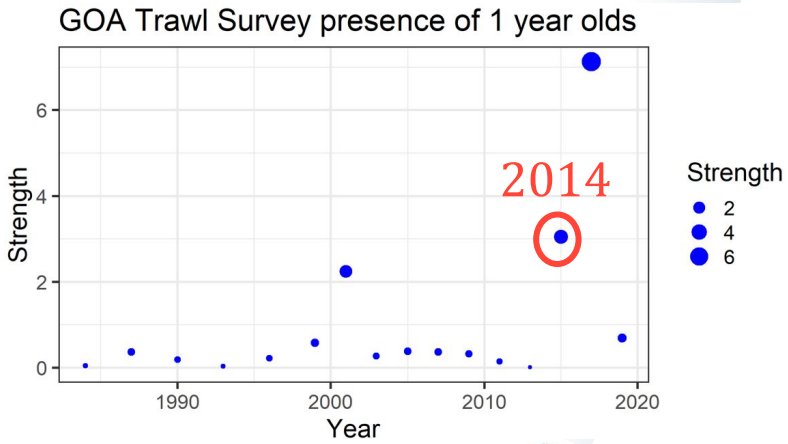
Steady decline with below average recruitment



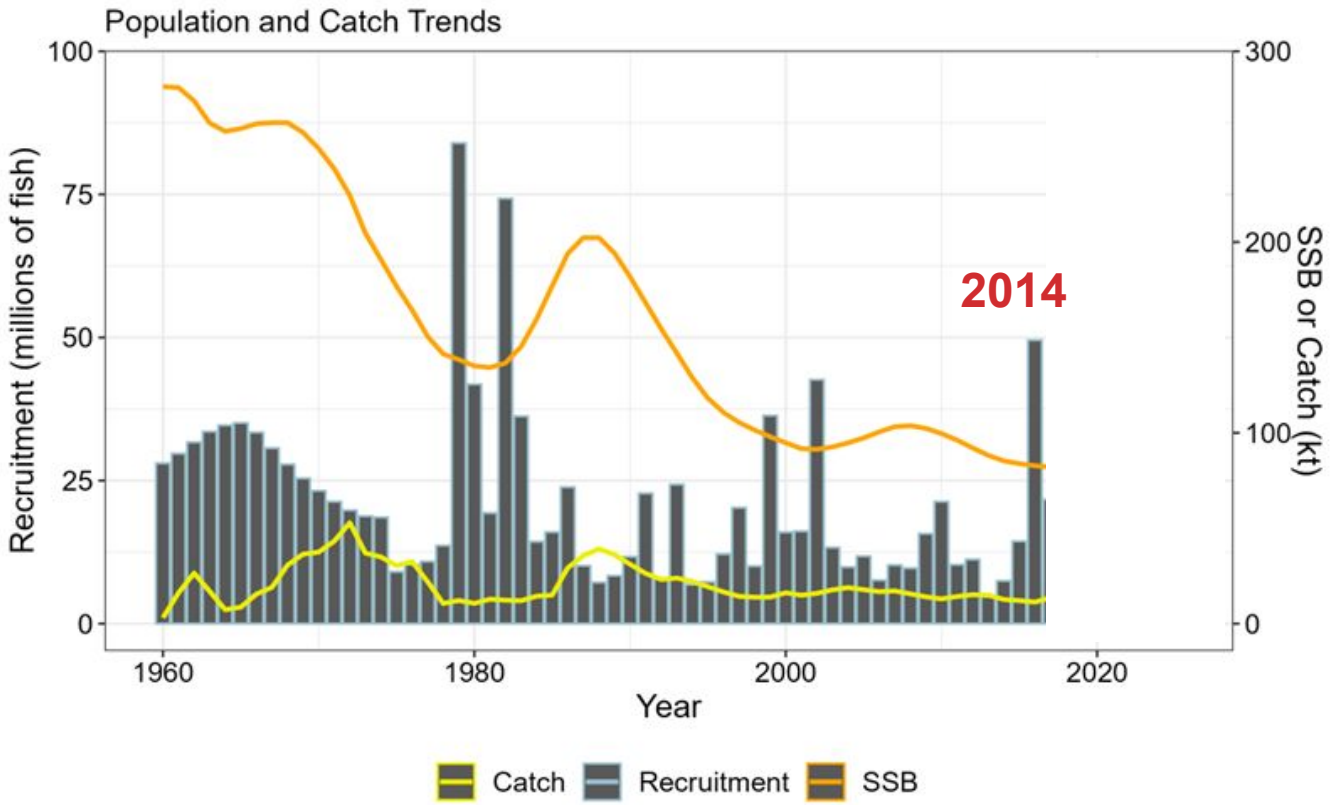
Early warning signs (2015-16)

- Reports of widespread abundance of 1 year olds
- GOA bottom trawl survey 1 year olds
- Southeast AK hatcheries
- Concurrent signs of small fish in WC and BC fisheries
- Longline survey caught significant 2 year olds in 2016

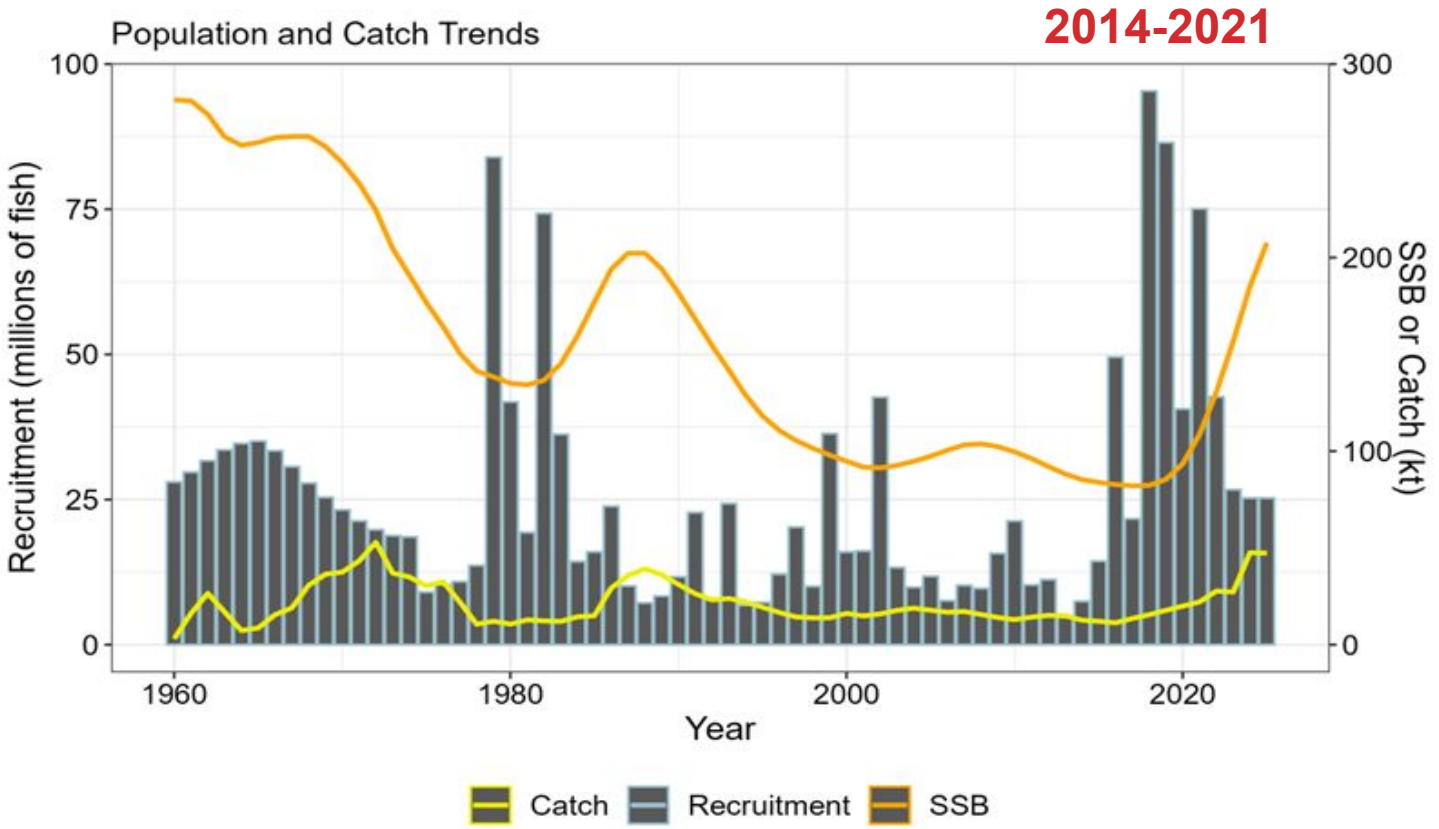




After a over a decade of declining quotas, help is on the way!

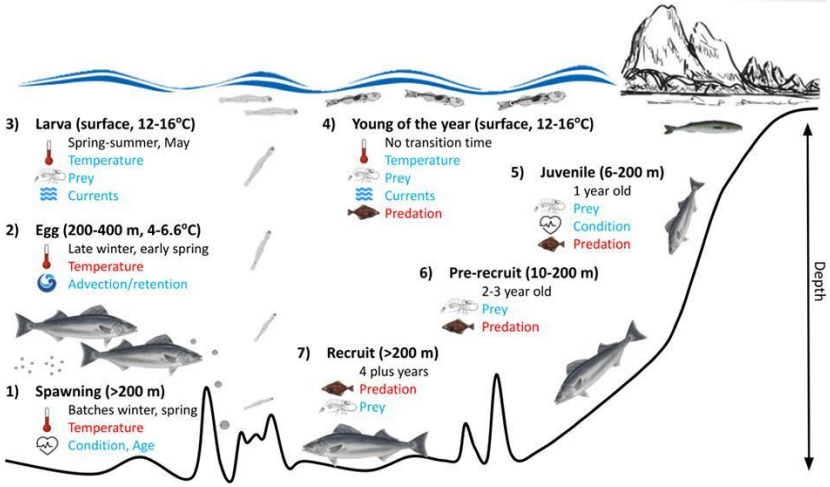


Too much of a good thing?



The response

- Enter the Ecosystem and Socioeconomic Profile (ESP)
  - Started in 2017 with sablefish, produced annually
  - Four step process to evaluate indicators at the stock level (complimentary to ESR)
  - ABC and TAC considerations
- Enter risk tables
  - Started in 2018 for sablefish, produced annually
  - Evaluate concerns external to the stock assessment model to inform ABC

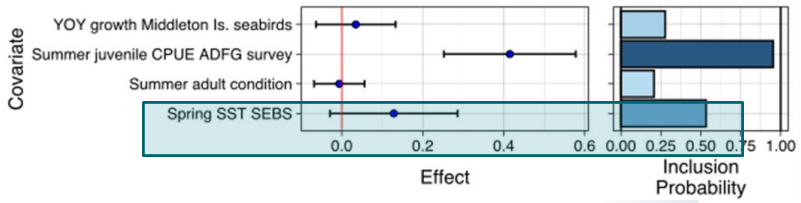


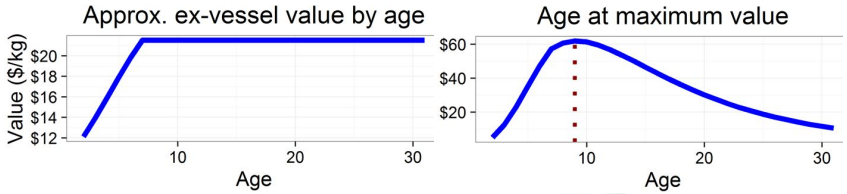
Shotwell et al. (2023)

The response

- Qualitative
  - Large and uncertain year classes in 2014, 2016, 2017, 2019
  - ESP indicators on fish condition, mean age, prey availability, spatial overlap with competitors all poor
  - ESP indicators referenced and reflected in risk table scores
  - **45%, 57%**, and **57%** recommended reduction in max ABC for 2018-2020
- Quantitative
  - Two high importance indicators related to recruitment (survey, temp)
  - Age at maximum value expanded to population ~9 years **(TAC)**

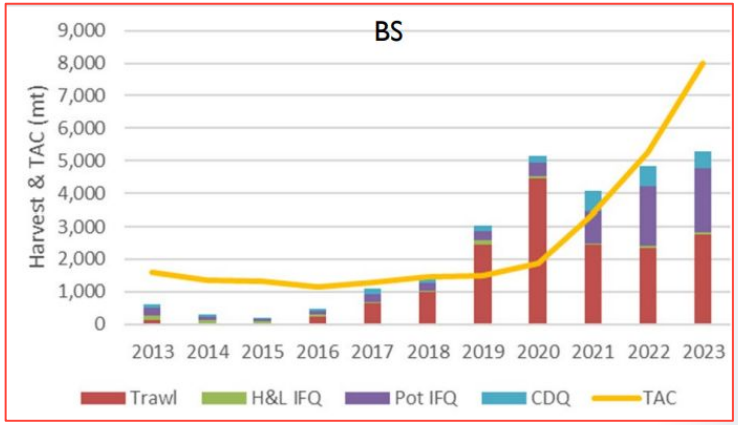
Indicator	2017 Status	2018 Status	2019 Status	2020 Status	2021 Status
Summer Sablefish Age-1 GOA Survey	*high*	NA	neutral	NA	neutral
Annual Sablefish Mean Age Female Adult Model	neutral	neutral	**low**	**low**	NA
Annual Sablefish Age Evenness Female Adult Model	**low**	**low**	**low**	**low**	NA
Summer Sablefish Condition Female Age4 GOA Survey	**low**	neutral	**low**	neutral	NA
Annual Arrowtooth Biomass GOA Model	neutral	neutral	neutral	neutral	NA
Annual Sablefish Incidental Catch Arrowtooth Target GOA Fishery	**high**	**high**	**high**	neutral	neutral
Summer Sablefish Condition Female Adult GOA Survey	**low**	neutral	neutral	neutral	neutral

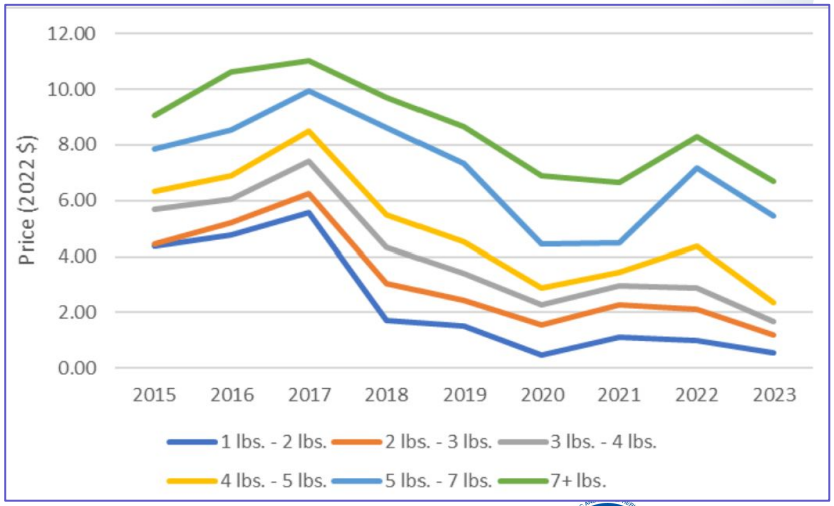




The results

- Massive population/quota shift to EBS
  - Increase in discards
  - Increase in trawl catch
- Markets
  - Price disparity increases for size grades
  - Overall decline in price even at large sizes
- Small sablefish release motion





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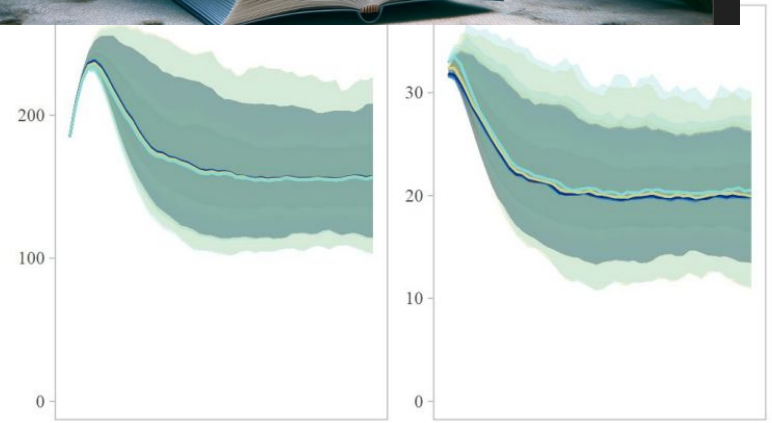
Lessons learned

- Current ABC control rules are weak for maintaining catch stability and population age structure
- TAC considerations could be better informed with assessment results
- Risk tables are helpful for ABC reductions during uncertain times
- ESPs can inform both risk tables and TAC considerations
- Need short-term climate/ocean projections for early warnings
- Big population changes will always require some adaptive management



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Scenario 3, best of both worlds
Scenario 4: Siloed management