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Alaska Fisheries Science Center

Climate related changes in abundance and range shifts of fish and jellyfish in the eastern Bering Sea, 2002-2015

PICES NBS Workshop Nov. 3, 2016

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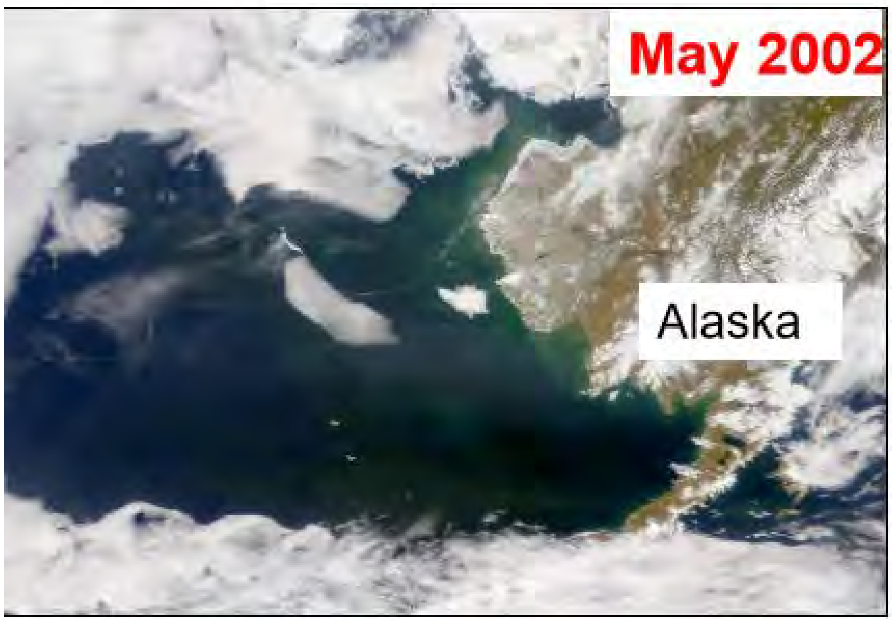
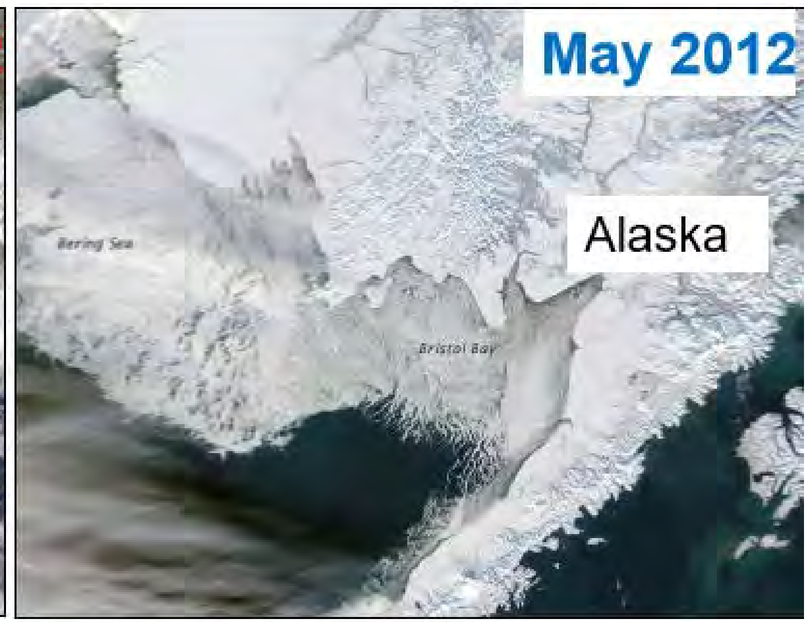
H1: MOVEMENT NORTH IN WARM YEARS

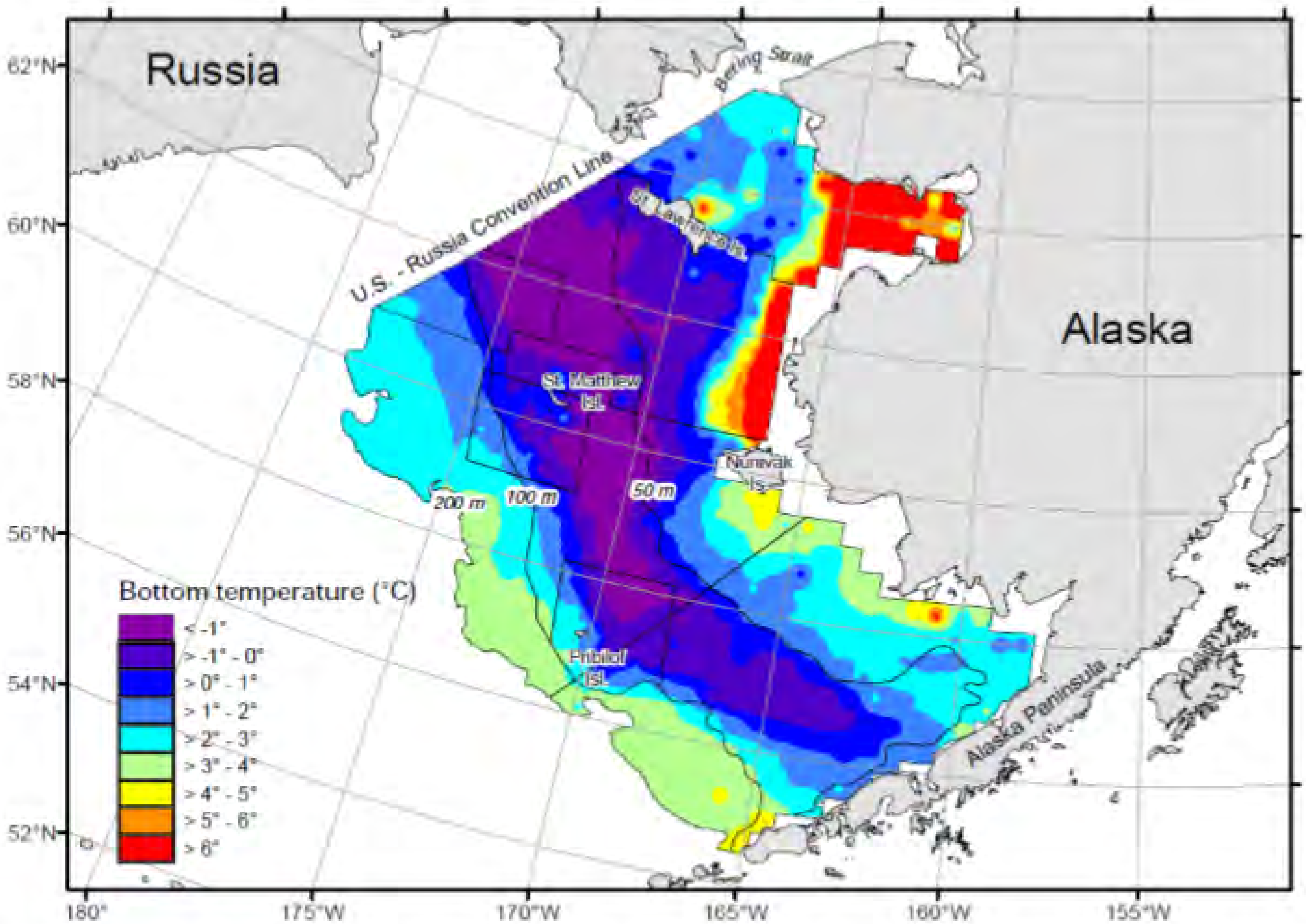
Spring Ice Extent

Warm years	Cold years
2002 to 2005	2007 to 2012



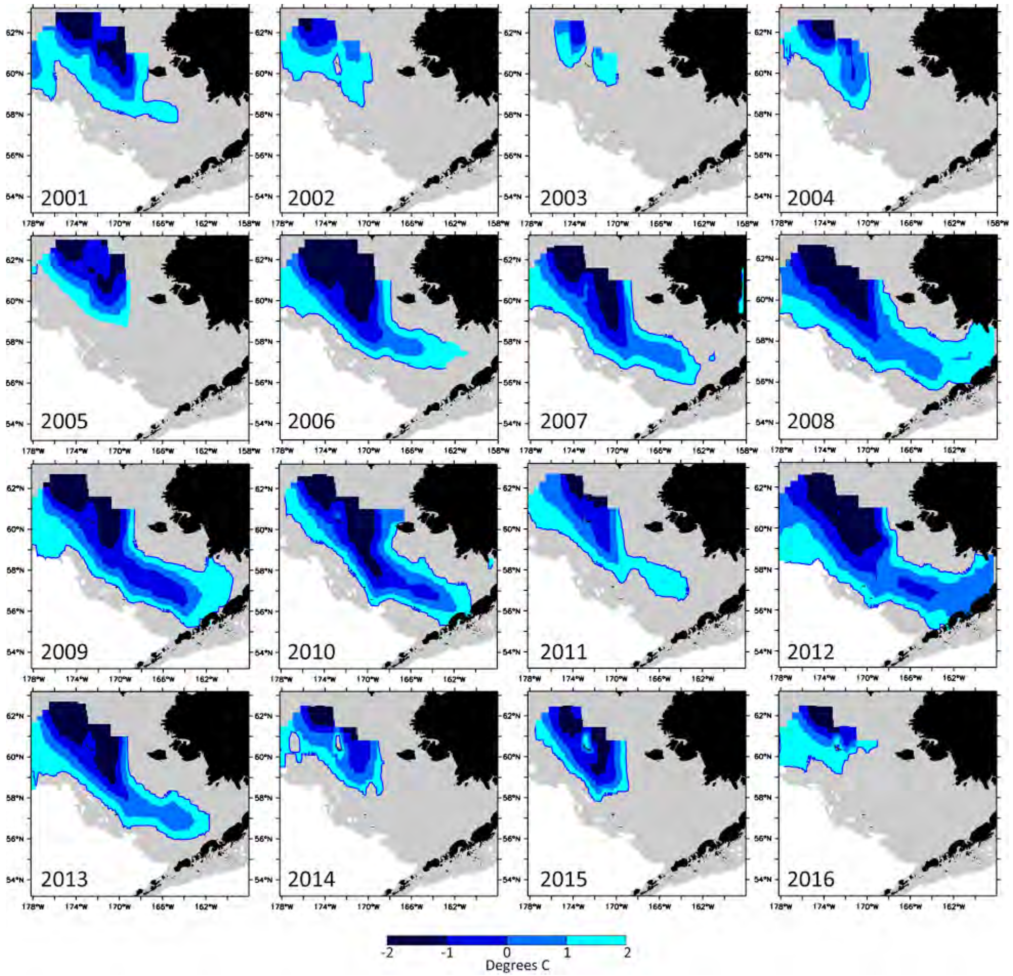


Sea ice melt forms a deep cold pool, barrier



Lauth, R. R. 2011. Results of the 2010 eastern and northern Bering Sea continental shelf bottom trawl survey of groundfish and invertebrate fauna. U.S. Dep. Commer., NOAA Tech. Memo. NMFSAFSC-227, 256 p.

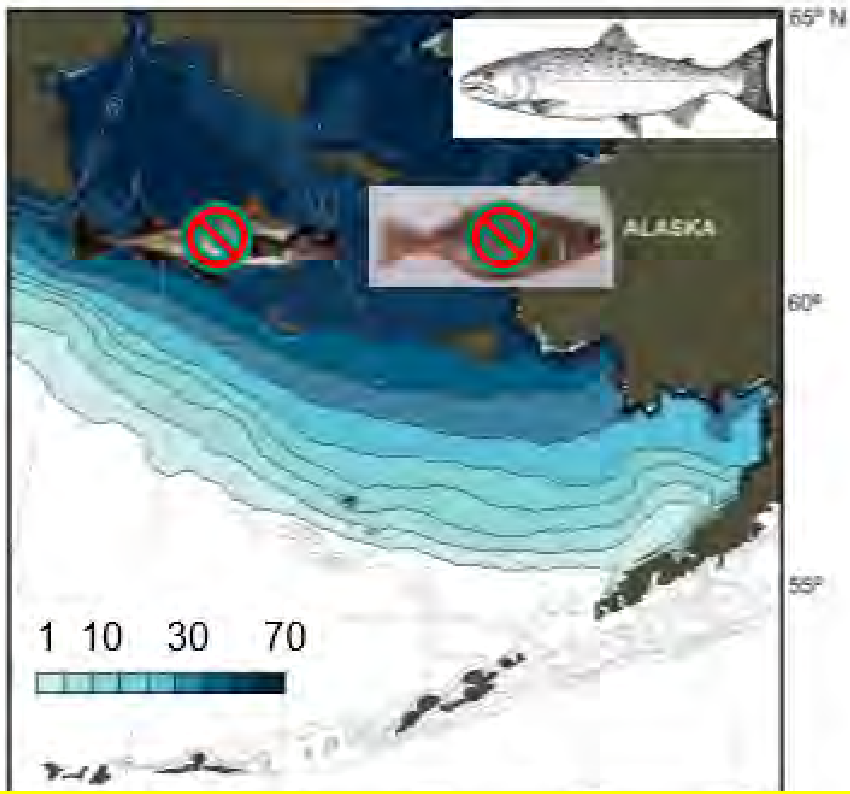
Cold pool extent: inter-annual variability



Lauth 2016

Less sea ice and smaller cold pool in warm years

Cold pool keeps bottom fish from moving north

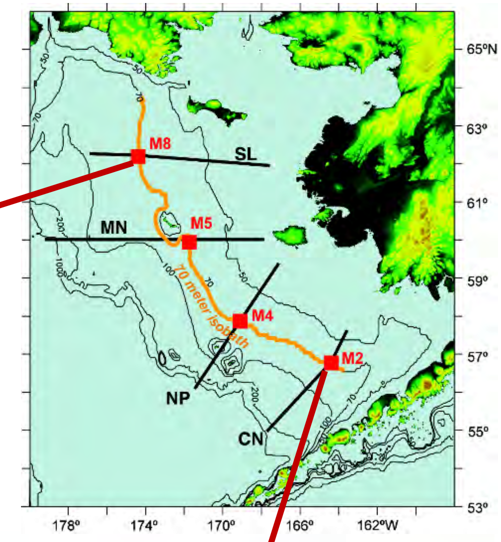


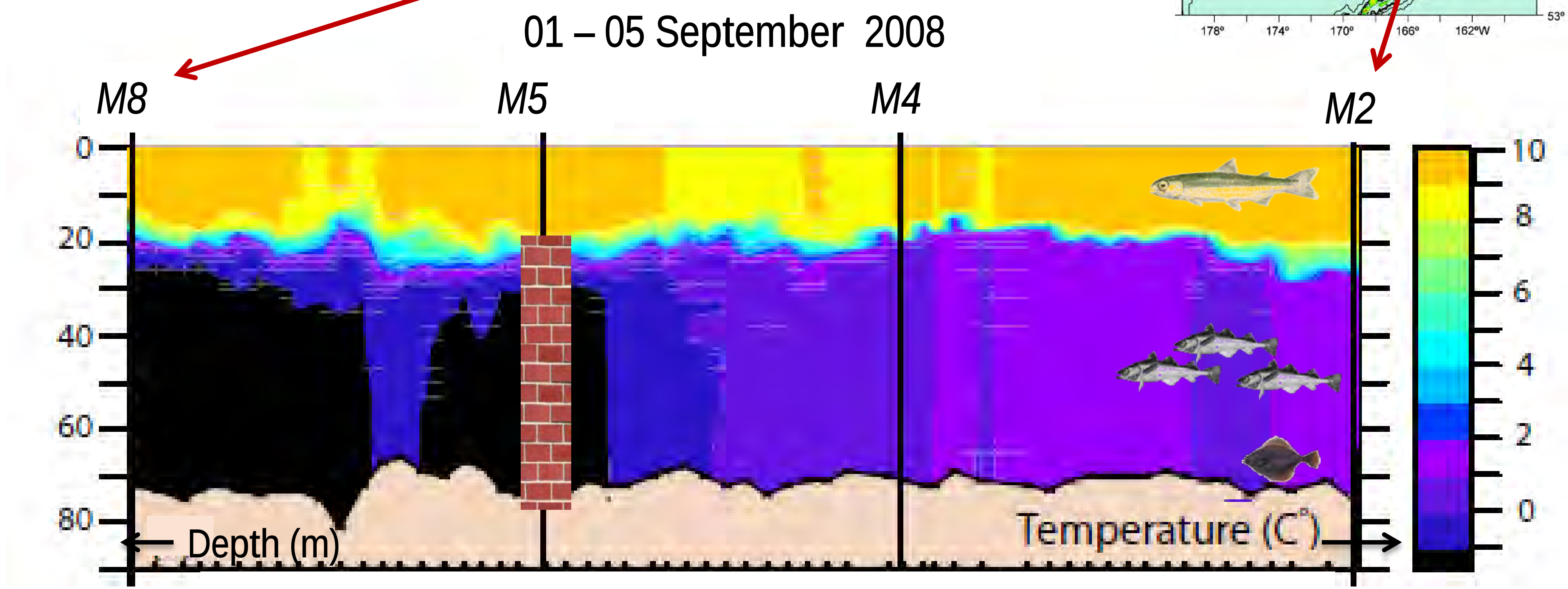
Pollock, cod, and flatfish avoid this cold bottom water, but not salmon

The average number of days in which sea-ice was present in March and April during 2001-2010.

Stabeno, P.J., E.V. Farley, Jr., N.B. Kachel, S. Moore, C. Mordy, J. Napp, J. Overland, A. Pinchuk, and M. Sigler. 2012. A comparison of the physics of the northern and southern shelves of the eastern Bering Sea and some implications for the ecosystem. Deep Sea Res. II 65-70:14-30.

Bottom fish avoid the cold pool, but pelagic fish are above it.

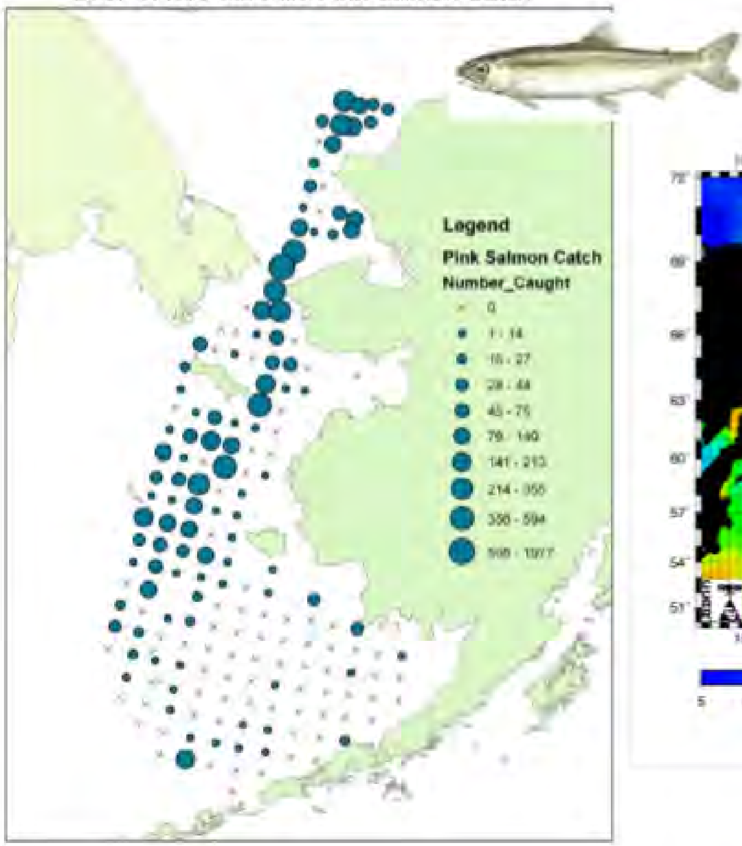




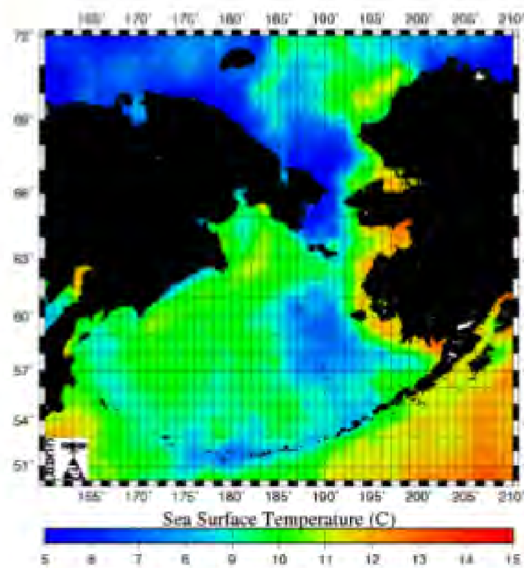
Stabeno, P.J., E.V. Farley, Jr., N.B. Kachel, S. Moore, C. Mordy, J. Napp, J. Overland, A. Pinchuk, and M. Sigler. 2012. A comparison of the physics of the northern and southern shelves of the eastern Bering Sea and some implications for the ecosystem. Deep Sea Res. II 65-70:14-30.

Juvenile salmon move north in warm (2007) & cold (2012-13) years

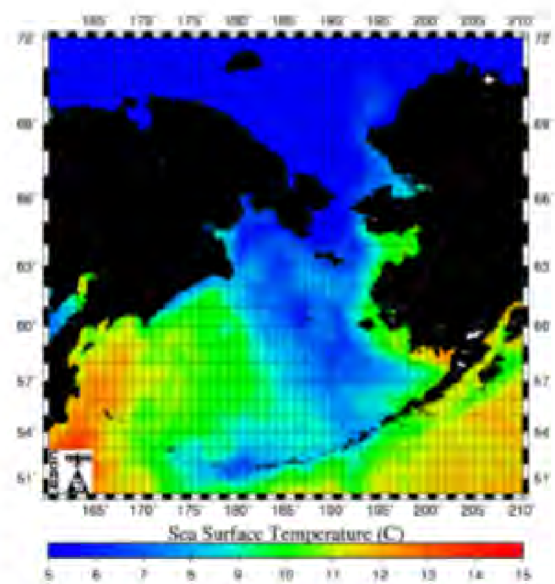
2007 BASIS Juvenile Pink Salmon Catch



Sep 13 2007



Sep 13 2006



Warm Year

Cold Year

Moore, S.E., L. Logerwell, L. Eisner, E.V. Farley, Jr., L.A. Harwood, K. Kuletz, J. Lovvorn, J.R. Murphy, and L.T. Quakenbush. 2014. Marine fishes, birds, and mammals as sentinels of ecosystem variability and reorganization in the Pacific Arctic Region. Pages 337-392, In. J.M. Grebmeier and W. Maslowski eds. The Pacific Arctic Region, ecosystem status and trends in a rapidly changing environment.

South of the cold pool, fish move north in warm years

Greenland halibut 98 km

Snow crab 89 km

Bering flounder 76 km

Arrowtooth flounder 46 km

Eulachon 34 km

Flathead sole 57 km

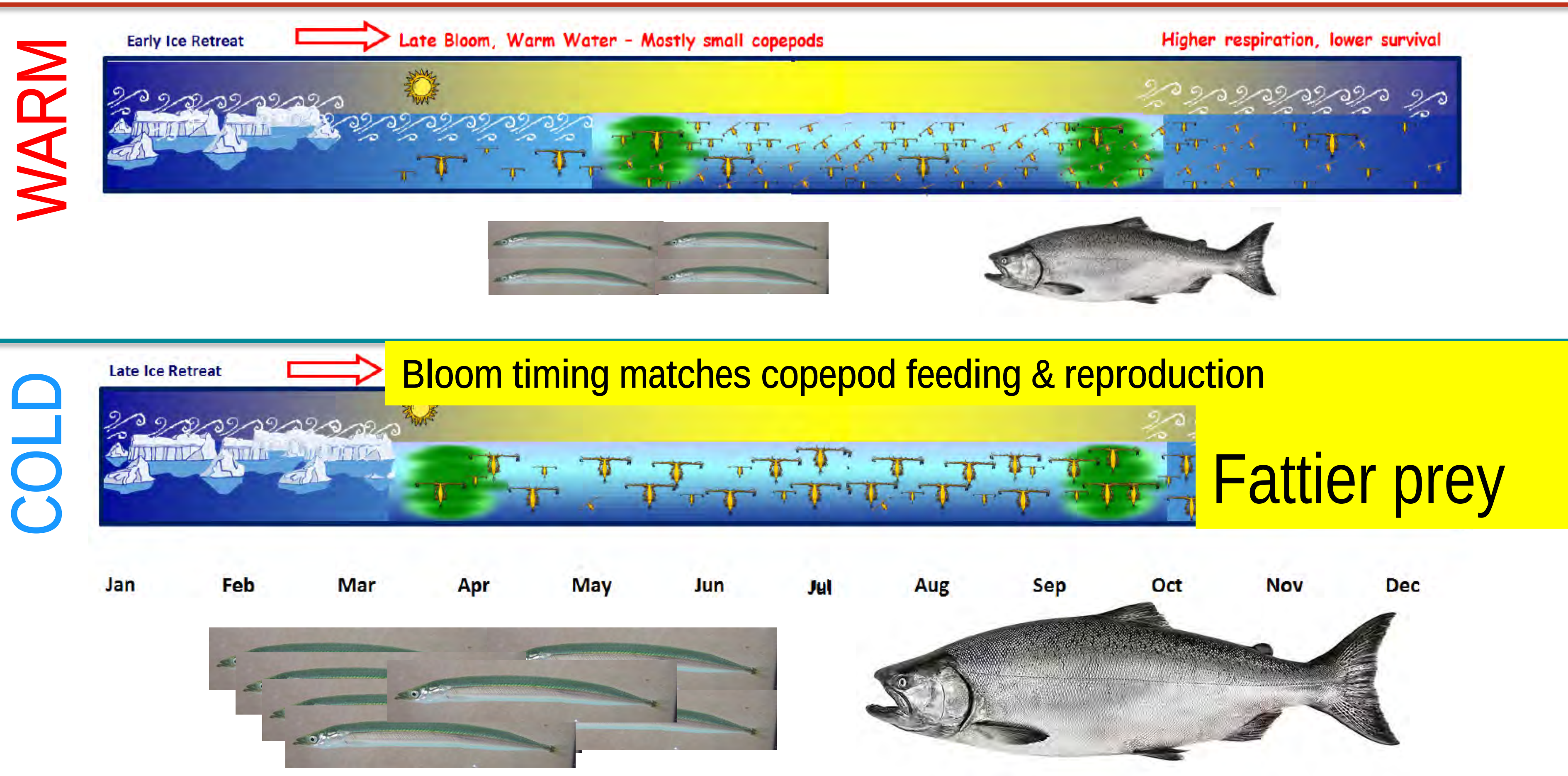
Pacific halibut 55 km

Bigmouth sculpin
Korean horsehair crab
Sablefish
Searcher
Skates
Yellow Irish lord

Mueter, F.J. and M.A. Litzow. 2008. Sea ice retreat alters the biogeography of the Bering Sea continental shelf. Ecol. Appl. 18: 309-320. Significant defined as $p < 0.05$. 1982-2006 Bering Sea bottom trawl surveys.
Also see: Spencer, P.D. 2008. Density-independent and density-dependent factors affecting temporal changes in spatial distributions of eastern Bering Sea flatfish. Fish. Oceanogr. 17: 396-410.

H2: ABUNDANCE WILL INCREASE IN COLD YEARS

Oscillating Control Hypothesis

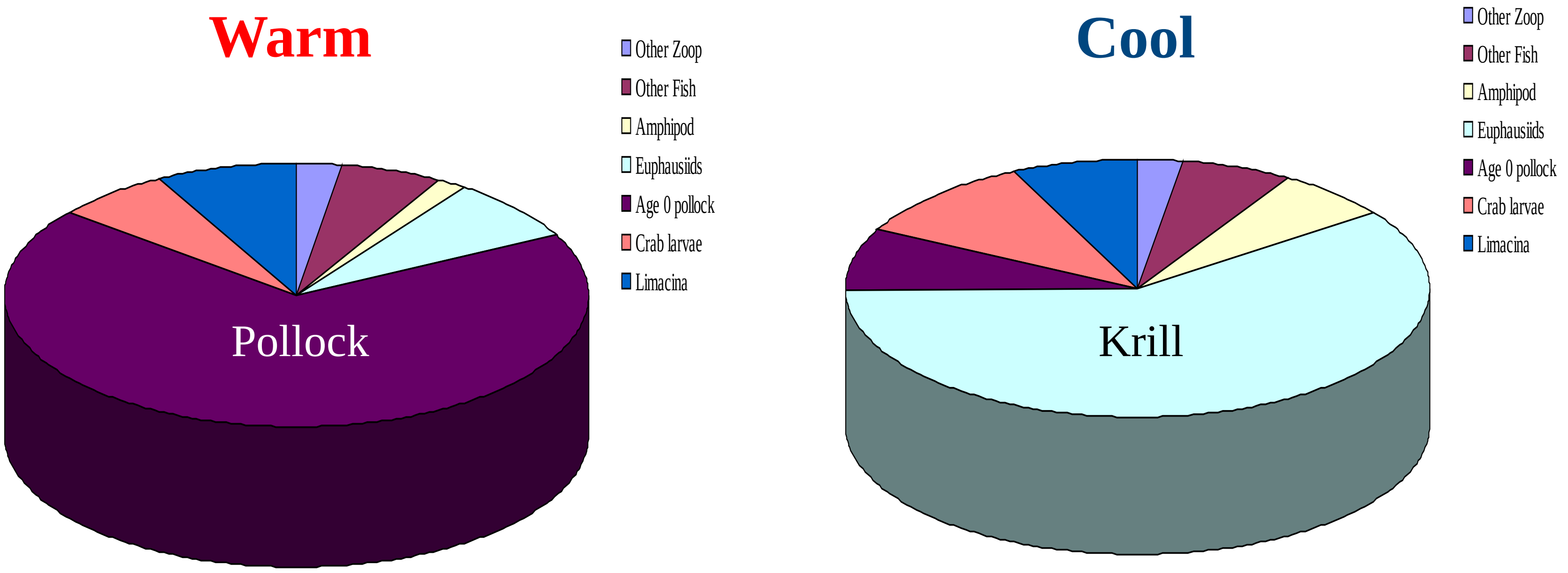


Hunt et al. 2011, Sigler et al., Yasumiishi et al. in prep

Cold = ↑ body condition, growth, survival

- Pelagic fish eat more lipid rich prey in cold years
- Higher intra-annual growth (kg) in immature chum salmon in EBS (Yasumiishi et al. 2015).
- Higher growth rates (mm) in juvenile Yukon and Kuskokwim Chinook salmon (Yasumiishi et al. in prep.)
- Higher fat content in juvenile sockeye salmon relates to higher marine survival (Farley et al. 2015).
- Higher lipid content in age-0 pollock predicts recruitment to age-1 (Heintz et al. 2014).

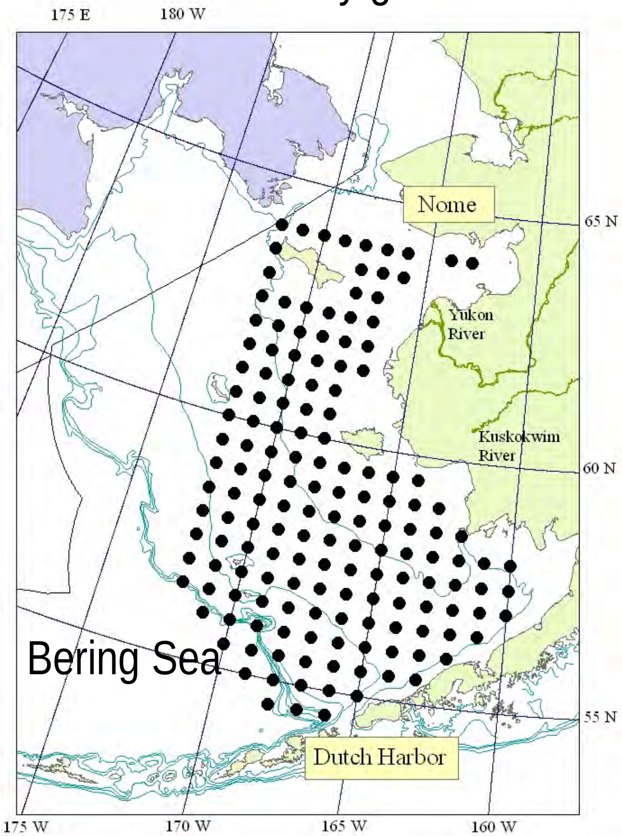
Cold = More krill (more lipids)



Juvenile sockeye salmon diets are more lipid-rich during cold years

Pelagic survey in the eastern Bering Sea

Survey grid



Surface trawl catches

2002-2015

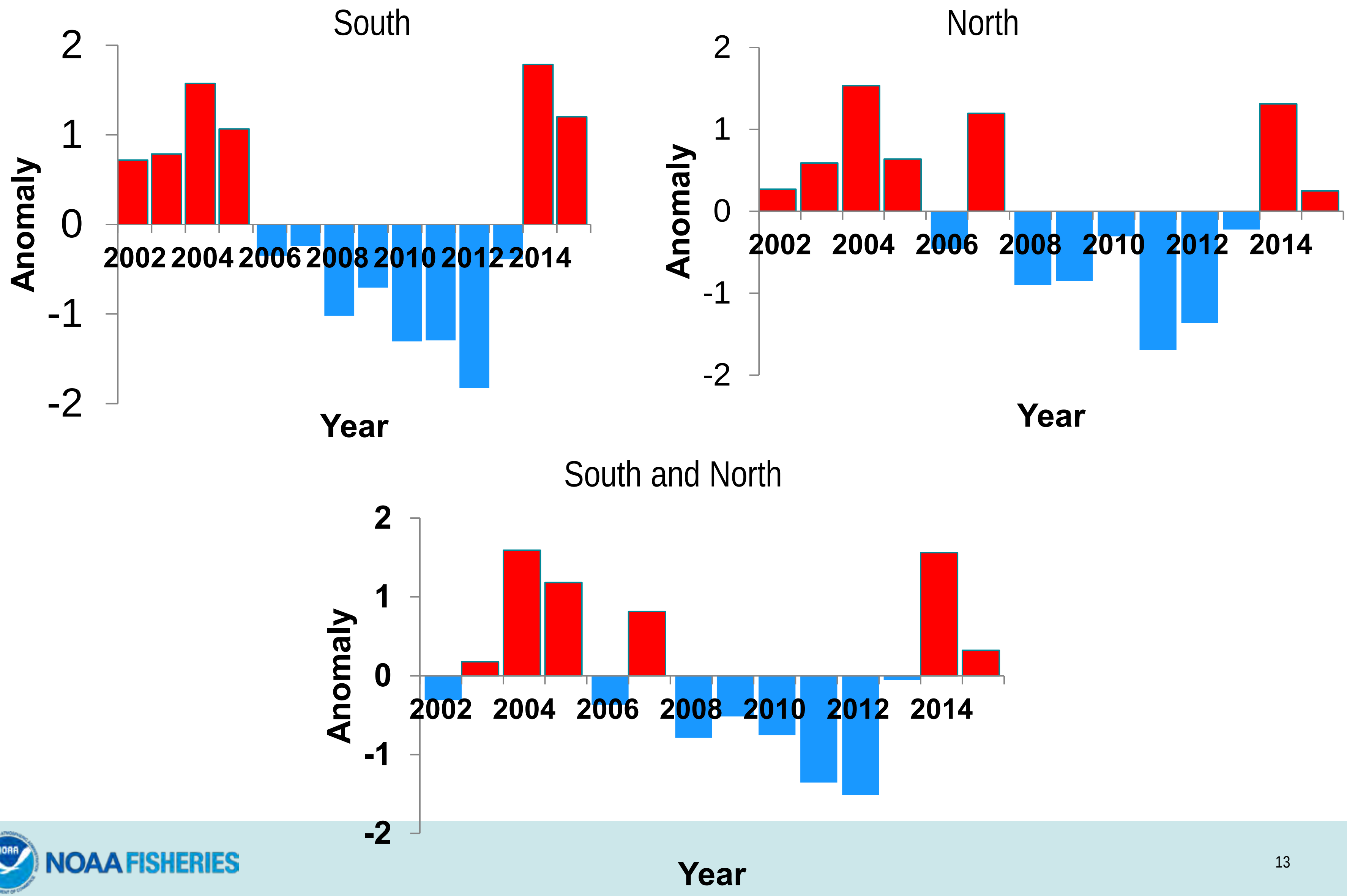
Missing data

2015 SEBS

2013 SEBS

2008 NEBS

Summer sea surface temperature



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Species of interest: catch data (kg)

Capelin *Mallotus villosus*

Pacific herring *Clupea pallasi*

Sea nettle *Chrysaora melanaster*

Sockeye salmon *Oncorhynchus nerka*

Methods: Geostatistical modeling

- **Anistropy plot**: to examine the east-west and north-south orientation of species.
- **Probability of capture plot**: to examine inter-annual spatial distribution.
- **Spatial Delta GLMM**: spatial-temporal model to estimate biomass from catch data.
- **Center of gravity (COG):** to examine shifts in distribution.
- **Regression**: Relationship between summer sea surface temperature and abundance and COG.

Statistical model and R code

- R software (R project)
- R packages: SpatialDeltaGLMM (v. 3l), ThorsonUtilities, TMB, INLA
- Github: nwfsc-assess/geostatistical_delta-GLMM
- Follow “best practices”

Methods: References

Anistropy plot, Probability of capture, and Abundance:

Thorson et al. 2015. Geostatistical delta-generalized linear mixed models improve precision for estimated abundance indices for West Coast Groundfish. ICES J. of Marine Science. 72(5):1297-1310.

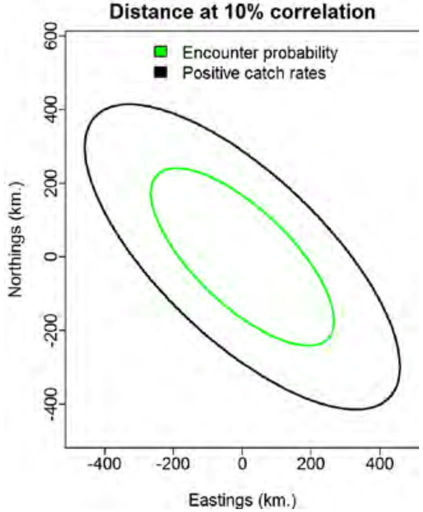
Thorson and Kristensen 2016. Implementing a generic method for bias correction in statistical models using random effects, with spatial and population dynamics examples. Fisheries Research. 175:66-74.

Center of gravity/Distribution shifts:

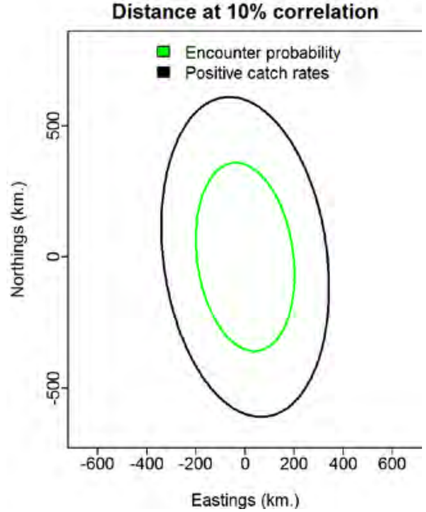
Thorson et al. 2016. Model-based inferences for estimating shifts in species distribution, area occupied and centre of gravity. Methods in Ecology and Evolution. 7:990-1002.

Anistropy (N-S, E-W orientation):

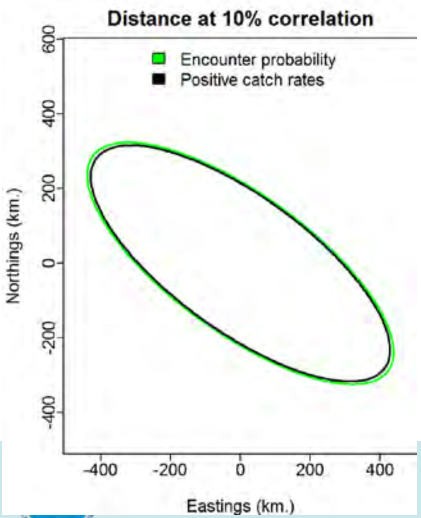
Capelin (NW 650 km)



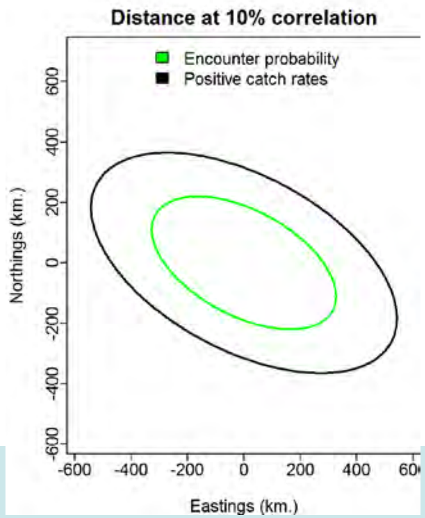
Herring (N 626 km)

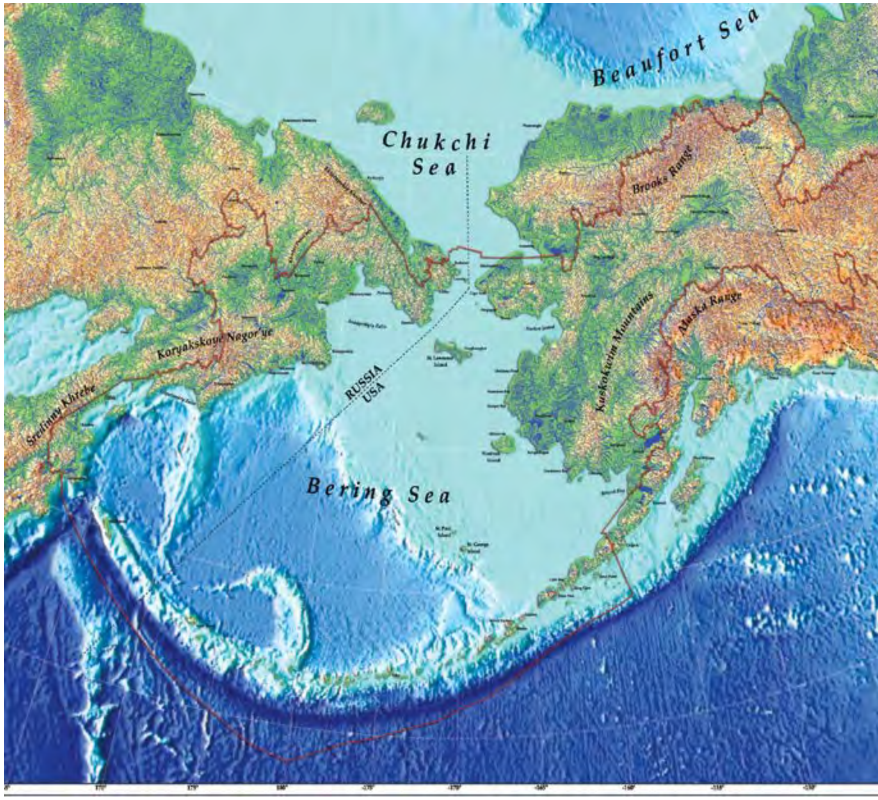


C. Melanaster (NW 1000 km)



Sockeye (WNW 700 km)



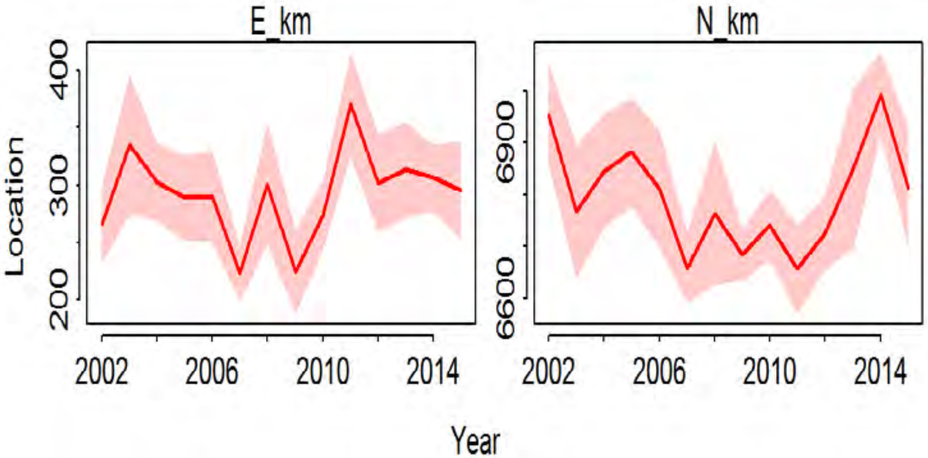


Encounter probability: Probability that the trawl captures the target species

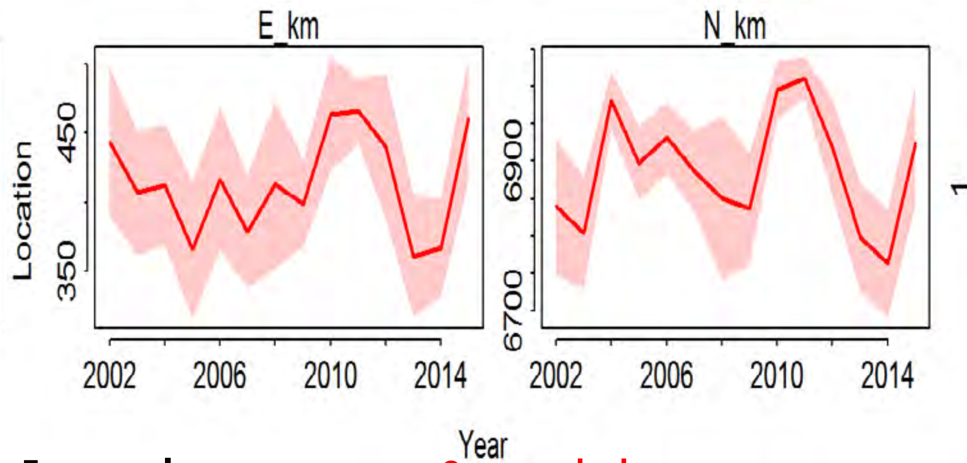
Positive catch rates: Positive catch rates given an encounter

Center of gravity (distribution)

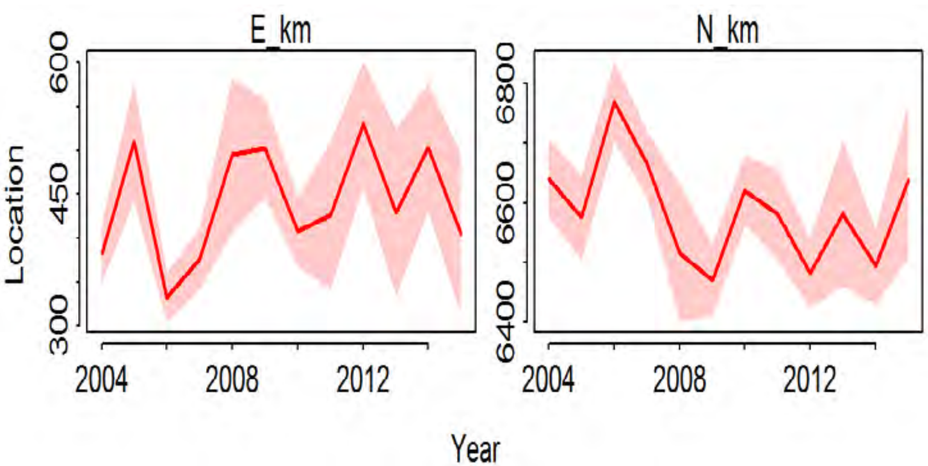
Capelin: north in warm years



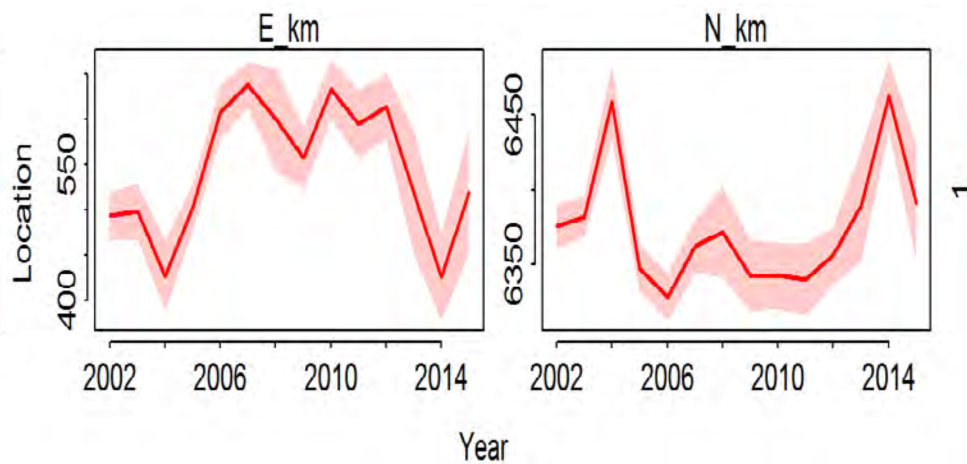
Herring



C. Melanaster



J. sockeye: west & north in warm years



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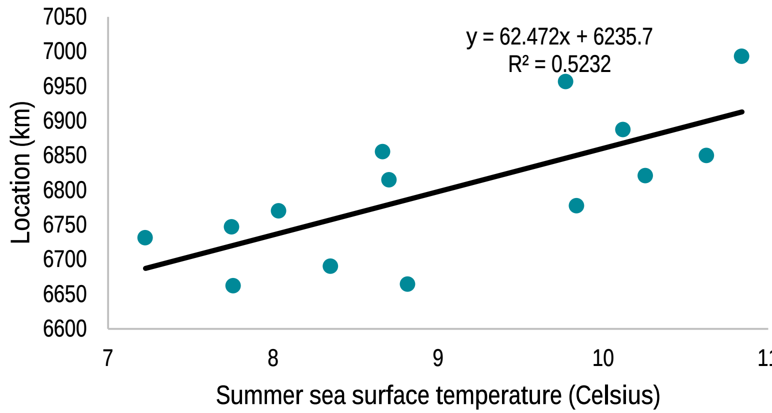
Universal Transverse Mercator

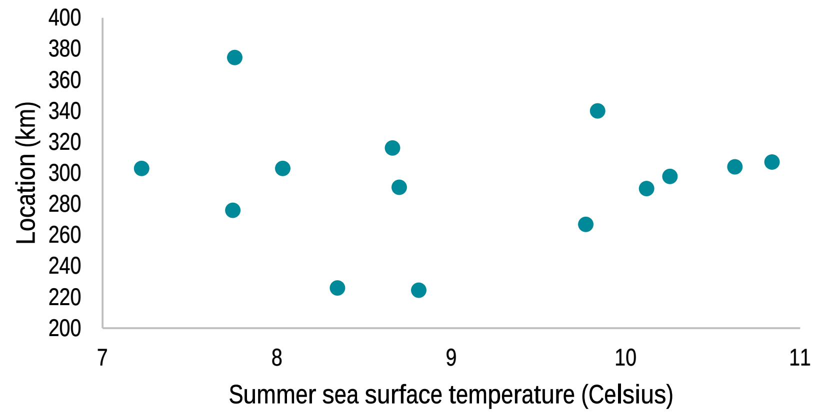
Climate related shifts in distribution

Capelin

Northward (62 km/ °C)

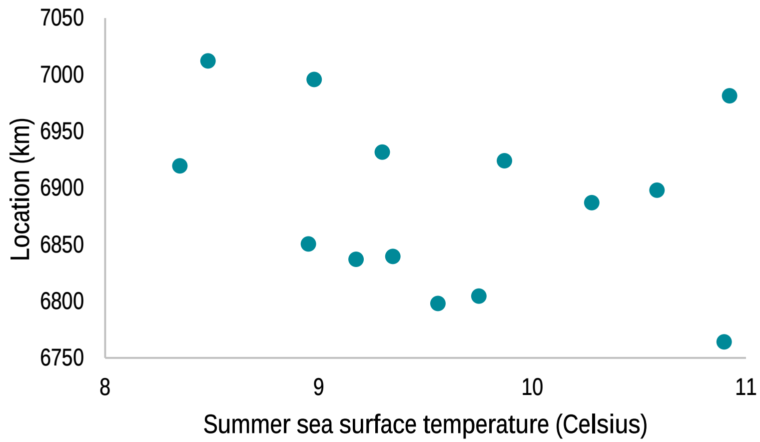


Eastward

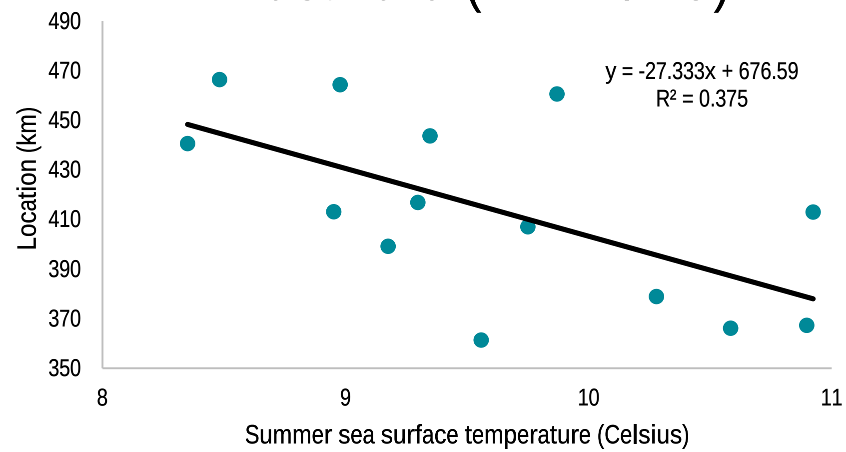


Herring

Northward



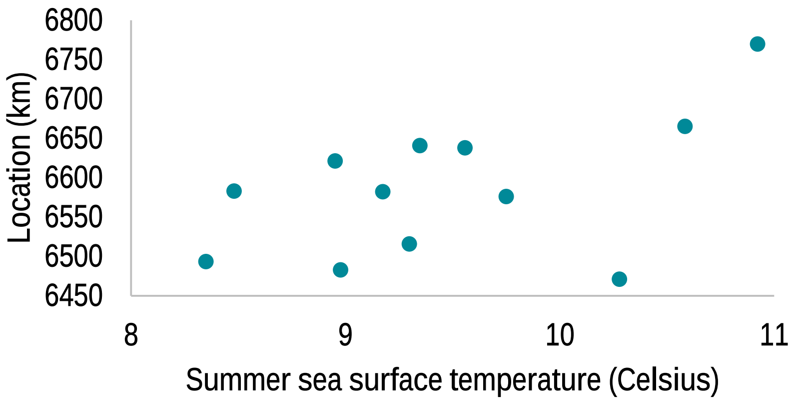
Eastward (27 km/ °C)



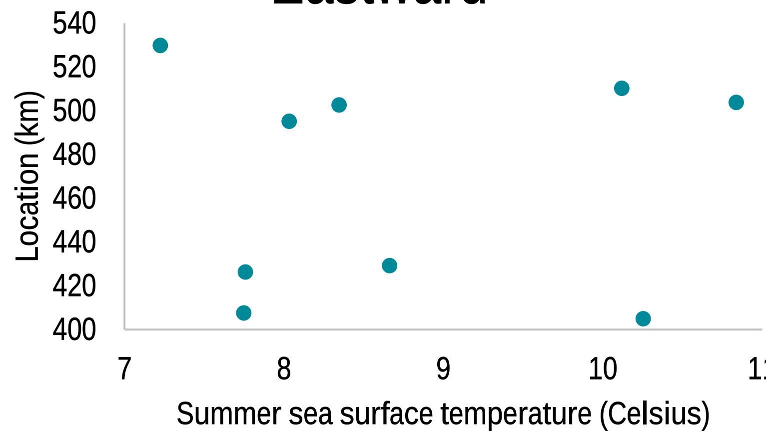
Climate related shifts in distribution

C. melanaster

Northward

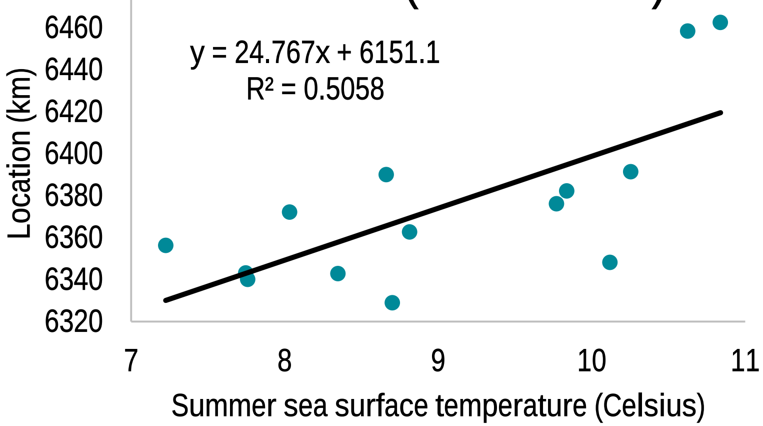


Eastward

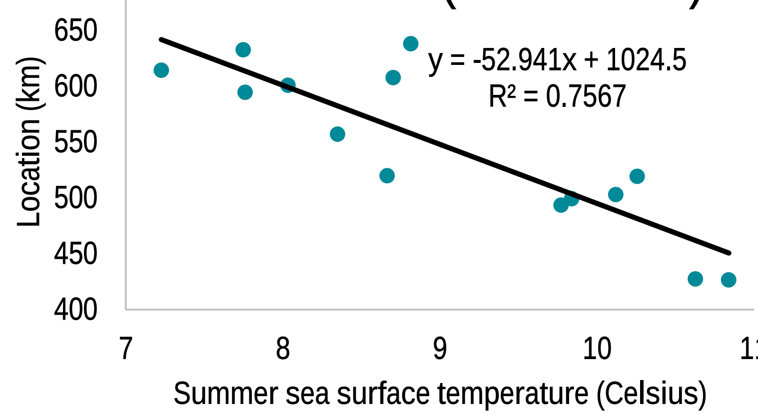


J. sockeye salmon

Northward (25 km/ °C)



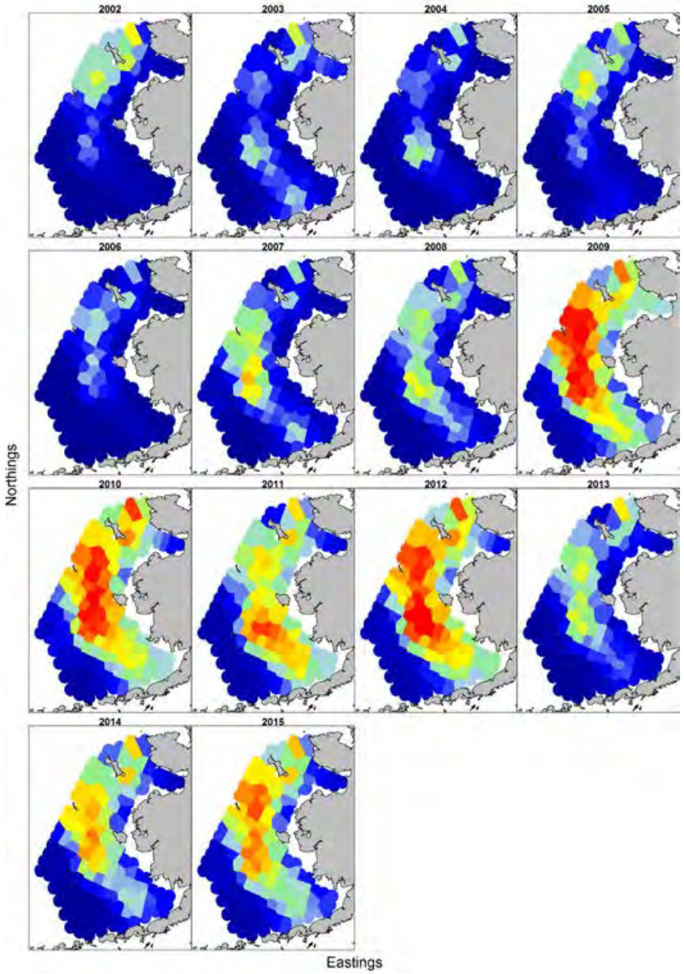
Eastward (53 km/ °C)

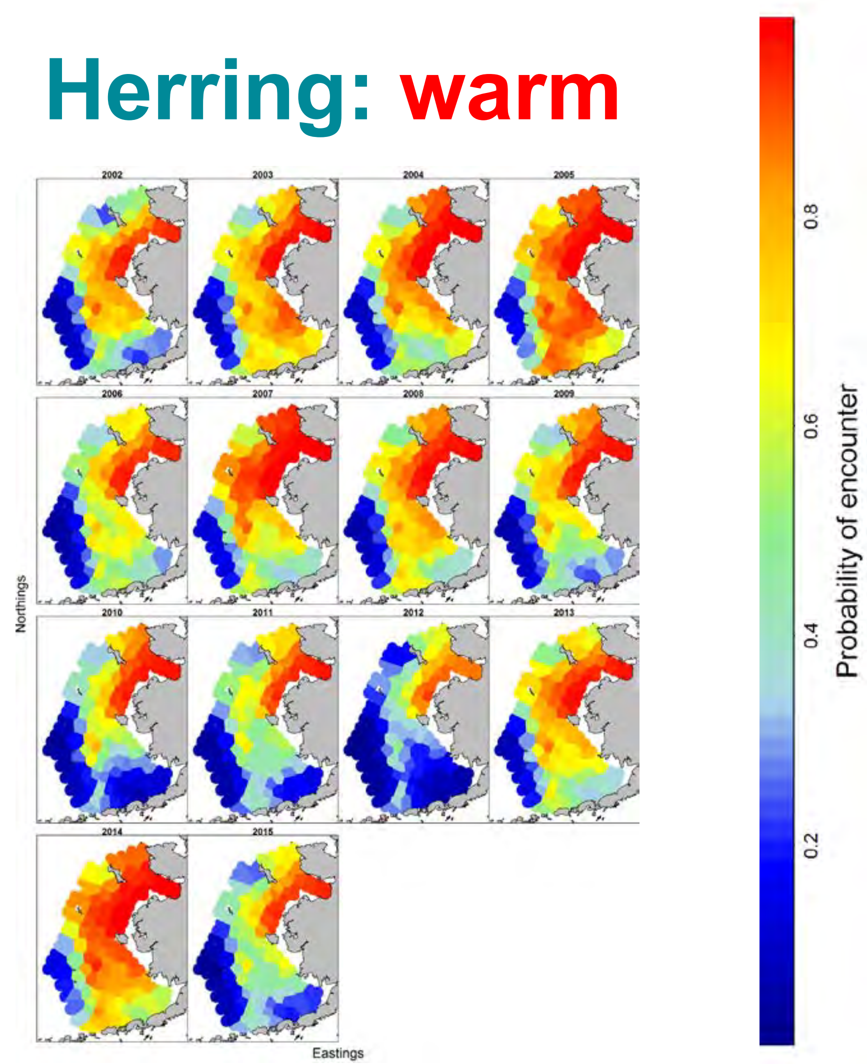


Probability of capture

Capelin: cold

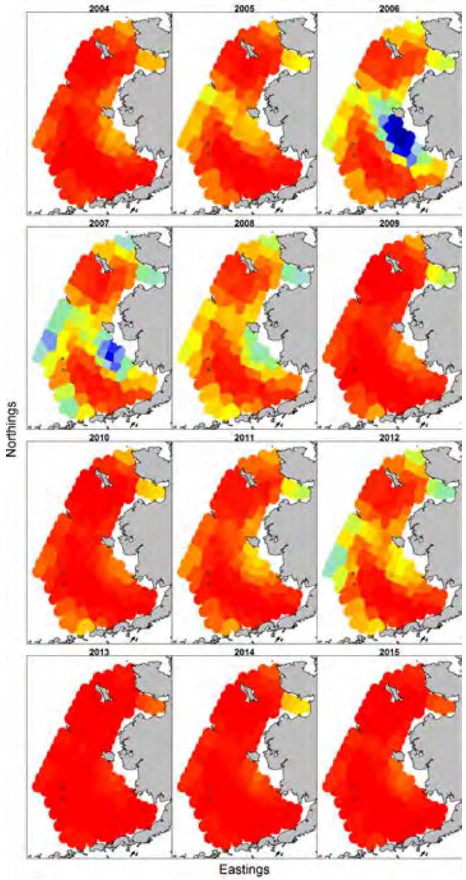
Herring: warm



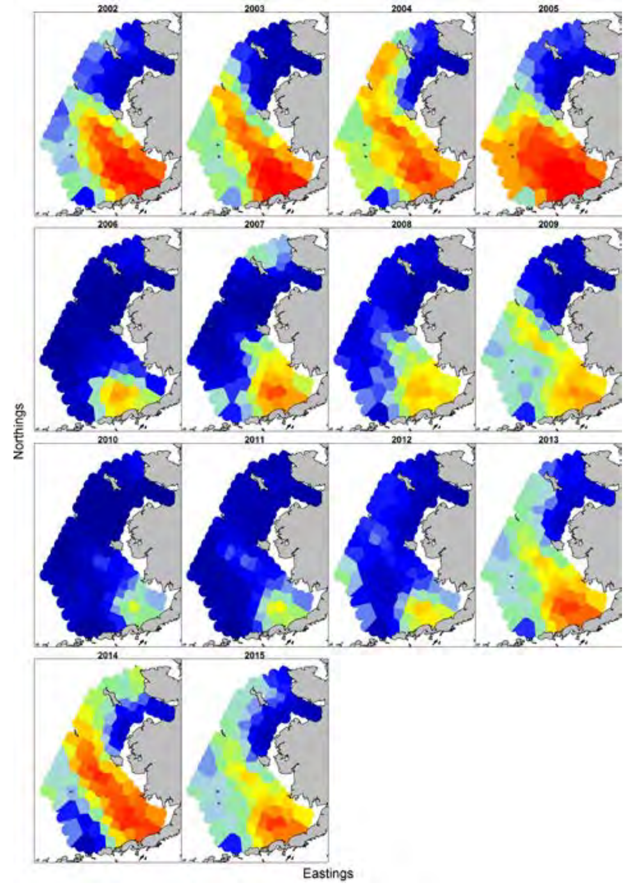


Probability of capture

C. melanaster:

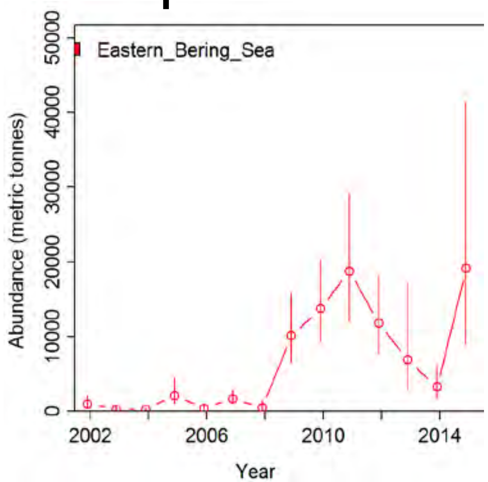


J. sockeye: warm

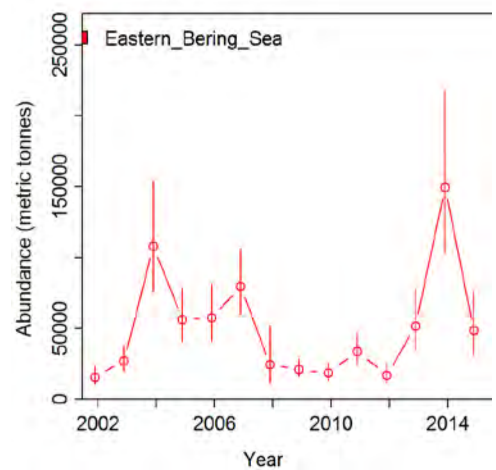


Estimated abundance: biomass (metric tonnes)

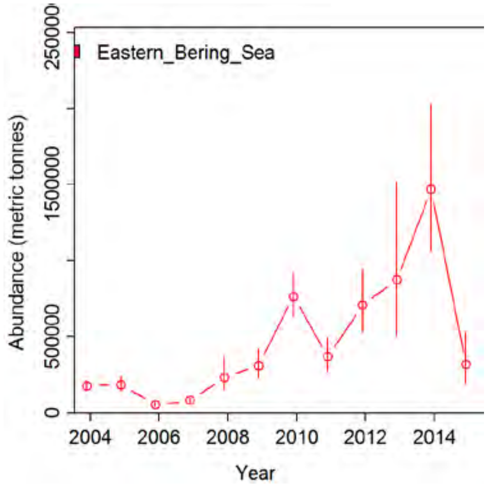
Capelin: cold



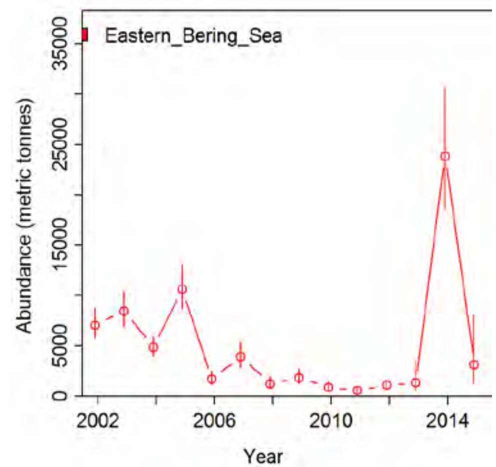
Herring: warm



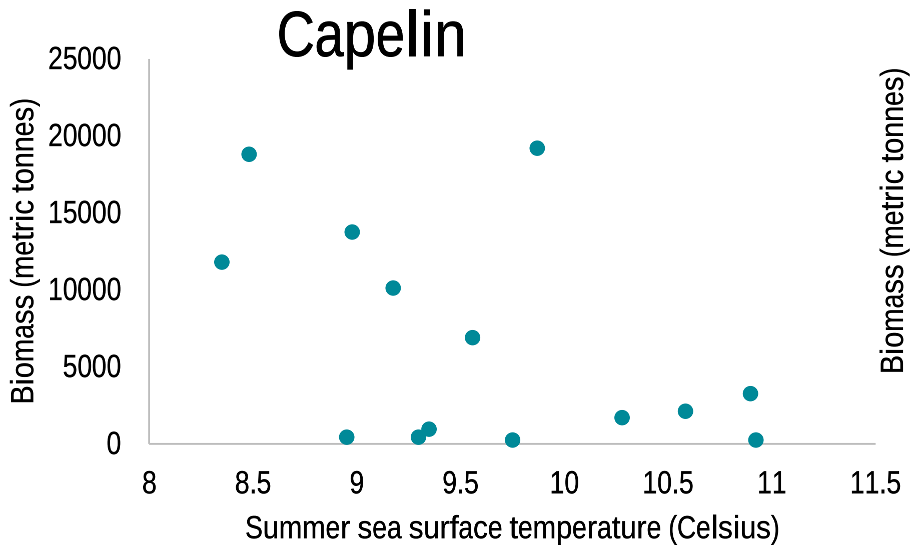
C. melanaster: cold

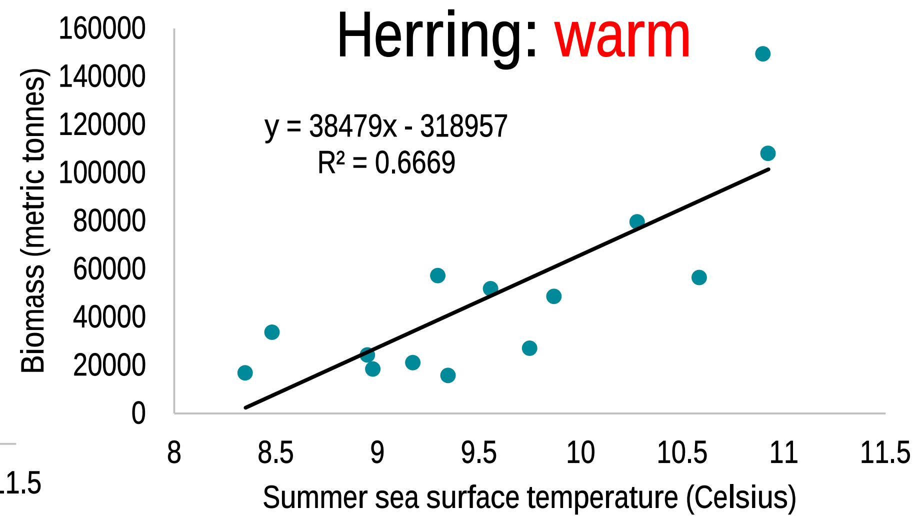


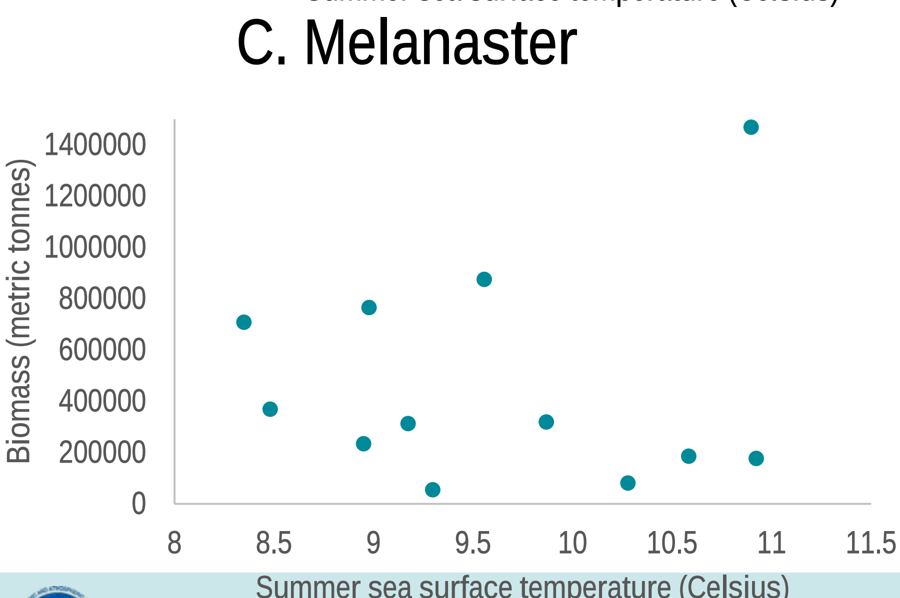
Sockeye: warm

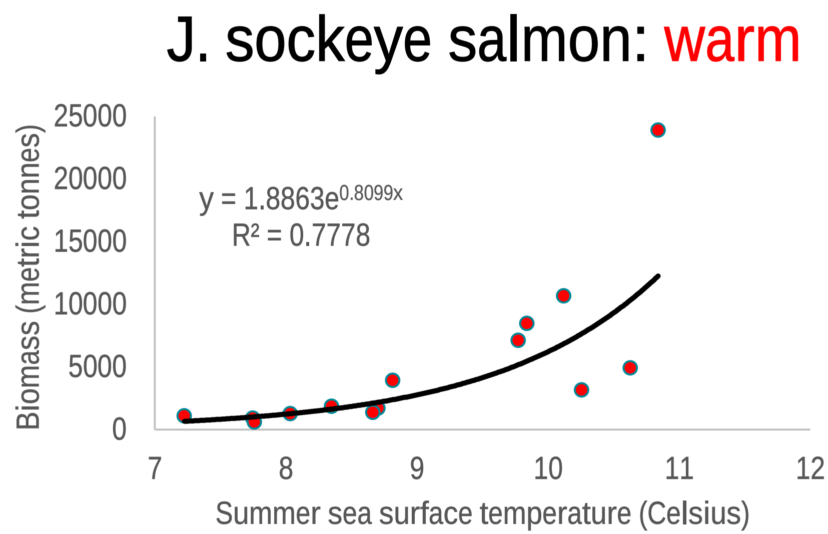


Climate and abundance









Summary

- **Distribution**:
  - Capelin and juvenile sockeye salmon were distributed farther north in warm years.
  - Juvenile sockeye salmon distributed farther west.
  - No difference in the distribution of herring or jellyfish in warm/cold years (highest biomass).

- **Abundance**:
  - Herring and juvenile sockeye salmon increased in abundant with summer warming.
  - Jellyfish biomass was negatively correlated with SST at a 2 year lag (t-2).

Implications of warming on the Arctic ecosystem

- **Distribution**:
  - Sockeye salmon and capelin will inhabit more northern waters providing pelagic forage for birds, mammals, and fish in the Arctic.

- **Abundance**:
  - Expect to see more herring and salmon. Possible fewer capelin and zooplanktivorous jellyfish (highest biomass species) may reduce competition for zooplankton.

  - Sockeye salmon will colonize new rivers in the Arctic, as observed Norton Sound rivers this year.

Thank you

Source code: Thorson (NWFSC)

Lauren Rogers (AFSC)

Ecosystem Monitoring and Assessment Program, AFSC